AN APPLICATION OF LINEAR REGRESSION
TO THE ALLOCATION OF
GENERAL PURPOSE VEHICLES

THESIS

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— John H. Golden

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Abstract

Thesis
The purpose of this ~~research~~ was to develop a mathematical model which could assist in the allocation of general purpose vehicles. The linear regression model developed was used, through the AFIT CSC computer system, within the SAS statistical software program.

Data was obtained from two AFSC bases. Their input, through the SAS interaction, led to the following model:

beta sub 1

$$Y \text{ (predicted maintenance cost)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

sub 1 sub 2

where X_1 equals age and X_2 equals average miles driven. The analysis demonstrated the statistical significance of the model. It also highlighted the potential for its application to include all bases within a command. The data limitation, only two bases in the sample, restricted the analysis from making any macro statements; however, it appears from the minor differences in regression coefficients, as well as similar mean fleet ages and mean miles traveled, the current distribution system is an effective one. This is to say that the current system of allocation used by the AFSC/LGT, the "fair share" method is effective at keeping maintenance costs, as well as vehicle assets, balanced across the AFSC fleet.

AN APPLICATION OF LINEAR REGRESSION TO THE
ALLOCATION OF GENERAL PURPOSE VEHICLES

I. Introduction

General Issue

The Air Force spends hundreds of millions of dollars annually for the replacement of motor vehicles. This replacement program is funded through the Air Force (AF) budget process. Within this process there is a program that funds USAF motor vehicles. This program is funded through an appropriation entitled Other Procurement-Vehicular Equipment (3080F). In fiscal year (FY 85, the AF received $332.6 million of the $337.4 million requested for vehicle replacement leaving a deficit of $4.8 million (2). This deficit will be compounded by the further program reductions, which are projected as a result of the Balanced Budget and Emergency Deficit Reduction Act of 1985 (30). This reduction, in addition to projected budget cuts, suggests that a review and analysis of how major commands distribute vehicles to their subordinate bases be undertaken. The analysis should suggest a distribution of vehicle assets that will produce the best return for the dwindling dollars available for this most vital AF resource.

An Overview of the Current Procedure

The current system of allocating general purpose vehicles is normally based on the "fair share" method. This method is based on an equitable allocation of vehicles from the major commands to their bases. The tool used to implement this distribution is the priority buy program.

The priority buy program is the tool by which the AF funds for and receives its motor vehicles. This program, which will be elaborated on later, is primarily a funding mechanism. This program basically matches the level of available funding for replacing AF vehicles to the number of vehicles which can be purchased. The key to the program is the use of five established priorities. These priorities are the means by which bases list their prioritized vehicle requirements. This process is guided by the AF Technical Order (AFTO) 00-25-249. The form which transmits the bases' requirements to their parent command is the Air Force Technical Order (AFTO) Form 468. It is through the interaction of matching available funds to a consolidated AF priority list that assets are obtained.

The priority buy program is the means by which the AF renews its vehicle fleets. It is the funding mechanism that through its five established priorities will set the numbers and types of vehicles that will be purchased (24). The basic document involved in this process is the AFTO Form 468. This form originates at the base level

transportation squadron. This form lists requested vehicles by the five replacement priorities, i.e., 1 through 5.

This process, the priority buy program, originates at the base level. From each squadron it goes through a series of thorough reviews. The first step in the review process is the one conducted at each major command (MAJCOM). At MAJCOM these reviews entail collating and analyzing each of AFTO Form 468s submitted from all subordinate bases. The result of this process is the formulation of a command-wide buy package.

This package is then forwarded, through another set of reviews, to HQ USAF Transportation (HQ USAF/LGT) for final approval. The details of this process will be expanded in the literature review portion of this thesis. After the funding levels have been established, through the priority buy process, the dollars are obligated to the General Services Administration (GSA). This is the point that the dollar figures, settled on during the priority review process, become real assets. This is done by sending the military interdepartment purpose request (MIPR) to GSA. Included in this request are the shipping instructions. These shipping instructions are provided to the item manager at the WRALC/MMV by the MAJCOM/LGT (24).

Statement of the Problem

The problem examined in this study is how to allocate new vehicles to bases so that the allocation will reduce the overall fleet cost. This problem will be examined from the point, in the vehicle buy process (priority buy program), at which general purpose vehicles are allocated from a command to its subordinate bases.

This research effort is a first step to quantitatively relate each base's vehicle maintenance cost related to a projected command vehicle maintenance cost line. A command vehicle maintenance cost line will be derived through a regression analysis. The application of regression analysis to this problem will be discussed in detail in the methodology section. These cost lines can show the major command Director of Transportation (MAJCOM/LGT) the predicted maintenance costs of the bases within the command. Specifically, this analysis will show the relationship between each base and the command average cost line. This cost line will be established from the regression of cost as a function of age and miles.

The Significance of Problem

The current "fair share" method of vehicle distribution attempts to allocate general purpose vehicles to keep fleets balanced. This distribution attempts to ensure that the average age of each fleet is not skewed.

This ensures no one fleet is substantially older than the others within a command (13). So then, why is it important to pursue other approaches to this allocation method? The answer to this question is that with the current trends of decreasing government deficits, fewer dollars will be available to maintain and to replace vehicles. This situation will require that vehicle managers consider cost effectiveness when they allocate vehicles to their subordinate bases.

The impetus for pursuing this research is the budgetary axe that has fallen across almost all AF programs (30). Tighter budgets will continue to be a situation with which DOD decision makers must deal with. Recently, the magnitude of this future environment was highlighted by Secretary of the Air Force Aldridge. Secretary Aldridge noted that the future would be "much tougher" (32). He predicted that with defense monies harder to get from Congress, "some tough decisions will have to be made about how to best allocate our resources" (32). Even so, there are still a great deal of funds expended in the purchase of general purpose vehicles. In FY 85, 51 percent of the funds allocated for the vehicle buy program were expended on general purpose vehicles (1). Since these vehicles make up a large portion of each Air Force unit's fleet they will be the focus of this study. There are currently 76,493 vehicles that fall within the

category of general purpose vehicles. These vehicles are worth approximately $1.03 billion (24). This research effort is directed toward developing and testing a model to help MAJCOM vehicle managers effectively allocate general purpose vehicles to subordinate bases.

Another key program impacted by these cuts is the funding for AF operations and maintenance (O&M). This program provides the dollars necessary to maintain all base level activities. The maintenance of vehicles is just one of the activities that falls under the O&M umbrella. The O&M budget for FY 85 was reduced by $2.7 billion (1). This program, one of several, competes for increasingly limited funds.

With fewer dollars available to replace and to maintain AF vehicle fleets, it is vital to obtain the most maintenance per each O&M dollars. While the emphasis of this study is the cost reduction placement of vehicles, it is also concerned with increasing fleet effectiveness. This effectiveness is measured by the ratio that results with getting the most outputs (miles) for the least inputs (dollars).

The question of cost-effectiveness is especially critical in the overall scheme of the base environment. The key to effectively allocating new vehicles, where they will reduce the overall fleet cost, is the potential for

cost avoidance. This cost avoidance can be recognized by reducing O&M costs.

This can be accomplished by effective placement of new vehicles. Effective placement of new vehicles should result in lower costs and higher utilization. This is a result of allocating vehicles where they reduce overall fleet costs. Additionally, this potential for cost avoidance increases in the long term. By allocating the new vehicles to the bases, with the highest fleet costs the MAJCOM will decrease the short-term maintenance cost. It will decrease long-term costs by placing newer vehicles at the high cost bases, as newer vehicles require less maintenance. The relativity of the long-term cost avoidance is the impact it has on the operations and maintenance costs. These costs represent 75 percent of the total costs of any system (23). By allocating the new vehicles where they can reduce the overall fleet cost, the command can then reduce costs both in the long and short term. This is one of the reasons behind the development of a method to analyze overall fleet costs. Figure 1 represents the total cost concept.

The following terms are defined as to provide the reader with a clear understanding of the significance of Figure 1. Purchase cost is the cost to obtain the item, in this case vehicles. Total cost is the sum cost of owning and maintaining the item. The operating cost is the

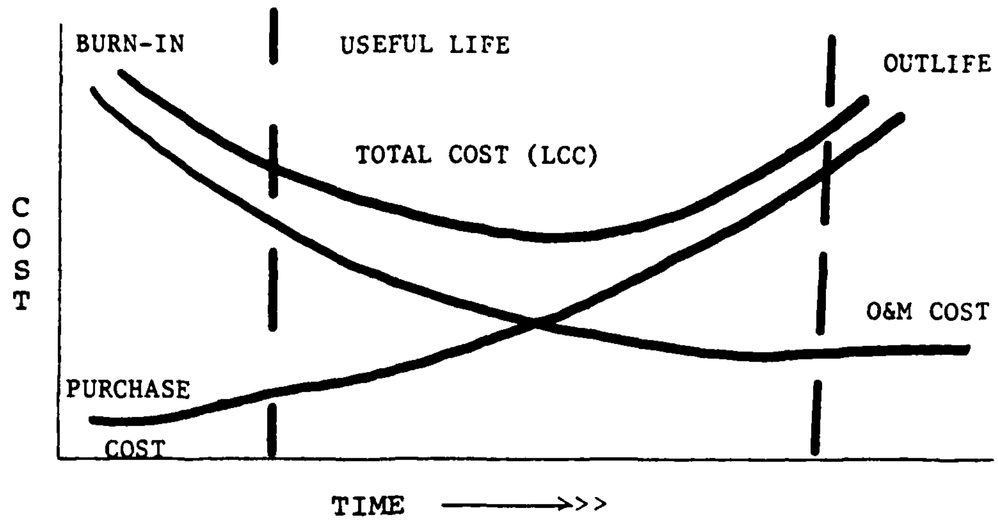

Fig. 1. Total Cost Concept (29)

cost of using the item and the maintenance cost is the cost of repairing the item to a serviceable condition (29). Four other terms relevant to this chart are: burn in; expected life; outlife; and reliability.

Burn in refers to the initial time of the life cycle for an item. Expected life is the expected usable time for an item, i.e., in the case of a sedan 7 years or 72,000 miles. Outlife indicates that period of time past the expected life portion of the item's life cycle.

Once a method is developed to analyze fleet costs it can be applied, in conjunction with current management practices, to make critical resource allocation decisions. These decisions will either be in the form of direct allocation of vehicles, or in the form of allocation of potential O&M dollars. The request for these additional O&M dollars will originate through a base level request for

unfunded requirements. These unfunded requirements will be channeled up through command. At command they will be processed through a command financial management board. If the request is funded then the dollars will be sent to the requesting base for the particular activity, i.e., vehicle parts funding, etc. The current situation is one where the decision maker will have to either pay now or pay later. This payment will take the form of either increased request for more vehicles or for more O&M funds. If the use of this model reduces the overall fleet cost, then there should be fewer requests from the bases for unfunded requests.

Research Question

The key question addressed in this study is: "How should new general purpose vehicles be allocated to bases by a parent MAJCOM so that both performance and cost are explicitly considered?" To answer this question, a mathematical allocation model will be developed and tested. This model will be based on the premise that scarcity of financial resources will continue to be a major constraint within the AF environment. As mentioned earlier, the current system of allocation involves a "fair share" method of distribution. This model will examine another approach to this problem of resource allocation. It will focus on placing the next general purpose vehicle at the base

where it will reduce the overall fleet cost within the command.

Limitations

There were two major limitations in this study. The first was that only general purpose vehicles were explicitly considered. Other vehicle types, e.g., fire trucks and special purpose vehicles, were not studied. Special purpose vehicles are usually allocated to meet specific mission criteria. The specific mission criteria for these vehicles relate directly to how they impact the AF flying hour program. Fire trucks and aircraft towing vehicles directly impact the launch and recovery of sorties. As such, these vehicle allocations are given extensive consideration by the MAJCOM Director of Transportion (MAJCOM/LGT).

The second limitation pertains to the data to be used in this thesis. Since January 1986 there has been an AF-wide conversion to the Sperry computer system. This conversion has resulted in the loss of historical data previously stored on the old computer system.

The loss of historical data also limited this research effort. Due to problems with the computer conversion the data base was made up of only one year's data. These data consisted of cost and usage factors associated with functional activities of several general purpose vehicle fleets within a major command. This resulted in

gathering Vehicle Management Reports (PCN 32) from two of the five bases in AFSC. These two bases formed up the general purpose fleet studied in this thesis.

Investigative Questions

This portion of the introduction of the investigative questions under study consists of two points. The first point defines some key terms used in this thesis. The second point lists the major investigative questions. These questions are the guidelines for the research conducted.

The two key terms used throughout this thesis are effectiveness and efficiency. A brief definition of these terms is provided to clarify the focus of this study. Effectiveness is defined as "doing the right thing," while efficiency has been defined as "doing things right" (20). Effectiveness, as defined above, relates entirely to cost avoidance. That is, placing the next vehicle where it will reduce the largest portion of the fleet (command) cost. This is what is meant as doing the right thing. This is as pursuant to the main tenet of this thesis. Further, effectiveness will be operationalized by using a regression model. The cost line created by the model will be used to assist in the allocation of vehicles.

The concept of effectiveness, as it is used in this thesis, is narrow in focus and centers around a certain function of allocation. The function of allocation as

viewed within the context of this definition of effectiveness is one of distributing vehicles where they will reduce overall fleet costs. The reason for this particular focus is that with the projected budget cuts and scarce resources, there will be fewer vehicles and dollars available to renew the AF vehicle fleet.

The following questions guided this research effort:

1. How do MAJCOMs currently allocate new general purpose vehicles?

2. How is the effectiveness and efficiency of the "fair share" method of distribution currently measured?

3. Can the proposed model demonstrate a distribution which can place the next general purpose vehicle where it will reduce the overall fleet cost?

4. Is the new model a valid approach to the problem of finding an effective and efficient method of allocation of vehicles to bases?

Methodology--An Overview

The quantitative analysis proposed in this thesis consisted of developing a regression model. This model predicted cost as a function of age and mileage. The data were provided by four bases within the Air Force Systems Command (AFSC).

The regression model consisted of one dependent and two independent variables. These variables were cost

(the dependent variable), age and mileage (the independent variables).

Once these variables are inserted into a statistical software package, a set of corresponding Beta values will be generated. The Beta coefficients will then be analyzed within the model. Following this analysis the results of the model will be discussed. The Beta coefficients represent interpretations of the intercept and of the independent variables.

For example, in the following regression equation $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2$, β_0 is the intercept which equals the average value of Y when each independent variable (X_1 and X_2) are set to 0 (41:49). The β_1 and β_2 values represent the interpretation of the slope. This slope of β_k represents the average change in Y with a unit change in Y_k (X_1 and X_2), when the other independent variables are held constant (41:52). This process allows each effect of X_k to be analyzed. In other words, β_1 is determined by X_1 and β_2 is determined by X_2. These Beta coefficients, once created, through the regression model, are multiplied by the X_k variables to establish the effect each independent variable has on predicting Y. In this study, it is the sum of $\beta_0 + \beta_1 X_1 + \beta_2 X_2$ that results in the Y value (the dependent variable).

As mentioned above, data from AFSC were analyzed through the use of the Statistical Analysis System (SAS)

statistical software package. SAS was selected because it was readily available and designed to meet the requirements of this research. While the particular methods used and the data collection procedures will be detailed in the methodology chapter, it is useful to discuss some of the basics of what was done.

Basically, data was transcribed from Vehicle Management Reports (PCN 32) reports submitted from bases within AFSC to a separate AFIT computer file. Once this file was created it was used through the SAS computer package to run several statistical tests. Then a regression model was developed and tested for a goodness of fit using the SAS package. The results of these runs are presented in the analysis chapter of this thesis.

Glossary of Terms

The following list of terms is presented to give the reader a clear understanding of the key terms used throughout this study:

CAFVIMS--Consolidated Air Force Vehicle Integrated Management System. This is an aggregate group of data, by command, which breaks out O&M costs by vehicle type and replacement code.

General Purpose Vehicle Fleet--those vehicles that are either commercial or military design type that are designed to move passengers and cargo. For the purpose of

this study, all B series vehicles were considered general purpose vehicles (25).

Commercial Design Type--this group is basically purchased "off the shelf" from major automobile manufacturers (25).

Military Design Type--vehicles which are designed for a specific military purpose, i.e., law enforcement peacekeepers (25).

PCN 32, Vehicle Management Report--is a monthly report which keeps track of all operations and maintenance costs (40).

USAF Management Code--the management code for the vehicle registration number contained in the PCN 32. For the purpose of this study, all B (general purpose) series vehicles were used.

Reg No--the vehicle registration number (40).

Period Use--in this case the miles traveled this period, as captured by the system. Since it is based upon fuel usage, actual updates and mileage corrections it may or may not represent actual miles driven (40).

Total Maintenance Cost this Period--the sum of total maintenance direct and indirect costs (40).

Labor--the cost of direct labor expended on the maintenance of a vehicle (40).

Total--the sum of in-shop direct cost of labor and materials used for the repair of a vehicle (40).

Contract--those costs which result from having a vehicle repaired commercially (40).

Other Government Agency--those costs of repair charged to the vehicle by other government agencies (40).

Summary

This chapter has introduced and discussed the problem under study. Also presented were the major research questions and the limitations of this thesis. Within the context of the research question, several investigative questions and key definitions were presented. Then an overview of the methodology used in this study was discussed. This chapter closed with a glossary of key terms.

II. Literature Review

Introduction

This literature review will address several topics, opening with a historical perspective of the status of vehicles within the macro view of AF budgeting. The next section provides a brief synopsis of the current philosophy behind the priority buy program. The following subject will consist of a brief analysis of the environment facing today's decision maker. The last two major topics discussed concern productivity and the vehicle acquisition process. Within the discussion of productivity, there will be an extensive definition of the concept and its application to the DOD.

The review focuses on corporate fleet management and the AF one-time repair limit (OTR). This portion will focus on the details behind vehicle replacement. The decision to repair or replace critically impacts maintenance costs, which will be defined in the next chapter, and is the focal point of this literature review. Within the context of this discussion, there will be a presentation of other methods employed in vehicle replacement. This is done to provide a better understanding of how vehicle replacement strategies are conducted, both in and out of

the DOD. Finally, the model used in this thesis will be introduced.

A Historical Perspective

The following philosophy provides an insight on why the procurement of vehicles fare so low in the AF budget process.

> When the Air Force became a separate service, there was a conscious effort to "start from scratch" and effect a complete break from Army procedures and traditions. The emphasis was on "flying and fighting." This was (and is) the Air Force mission, and commanders at all levels in the Air Force invariably emphasized aircraft operations and maintenance. Vehicles were considered along with desks, typewriters, tools, and ground communication gear. No consideration was given to the importance of vehicles as a collective system directly supporting the flying mission. (25:9)

This assessment continues to carry over into today's Air Force.

The low priority of acquiring vehicles continues to be reflected in the AF budget process. All vehicles are funded in the 3080F appropriation. This appropriation is under the generic umbrella of other procurement. Table 1 indicates the decreasing importance and funding of this program. While all areas of this appropriation received higher funding, the vehicular equipment area received the smallest increase. What this means is that there will be fewer dollars to obtain replacement vehicles. Fewer in terms of overall dollars available to the AF. Even with these limited funds, 51 percent of the available funds for

TABLE 1

BUDGETARY CONSIDERATIONS (1)

Appropriation, Other Procurement, Air Force Activity	FY 85*	FY 86*
Munitions and Associated Equipment	$ 883.4	$1,251.9
Vehicular Equipment	$ 317.0	$ 337.4
Electronics and Tele-Communications Equipment	$1,682.7	$2,297.8
Other Base Maintenance and Support Equipment	$4,074.9	$4,961.1

* In millions of dollars.

vehicles were used to purchase general purpose vehicles. It seems as though the historical philosophy presented will continue to be the one that prevails in the future management of the budget process.

The Current Philosophy Behind the Priority Buy Program

In the managerial problem-solving process of acquiring and managing vehicles, decisions are made on a quasi-quantitative basis. The MAJCOM/LGT gets inputs from his bases. Based on that data, he compiles his input to the command priority buy program and submits it through a number of processes. The final step in this process is Air Staff evaluation. The details of this process will be discussed later. The decisions made in the priority buy

and allocation process are based on using analysis that is more qualitative in nature. This decision-making process which is guided by this type of qualitative analysis is defined as: "one which is based primarily on manager's judgment and experience" (19:3). This process of allocation and vehicle replacement in other major fleet activities has been traditionally answered by manager's "gut feeling" (21:41). The major objective of this thesis is to introduce a workable quantitative model to assist senior managers in allocating general purpose vehicles.

Environmental Analysis

As mentioned earlier, the future environment of the DOD will be severely constrained by an ever-increasing scarcity of resources. This fact is the driving force behind an ongoing evaluation of AF programs. One of the major support programs, to the flying mission of the AF, to be impacted by budgetary cutbacks is the acquisition of motor vehicles.

In FY 85, 332.6 million dollars were allocated for the purchase of motor vehicles. The priority buy program is the way the (AF) sustains and renews its vehicle fleet. This program sustained a $4.8 million reduction in FY 85 and will likely be subject to further budget reductions resulting from the Gramm-Rudman-Hollings Act (2). This budget cut, and future projected cuts, will require the AF to do more (higher outputs) with less resources (fewer

inputs). This push for increased productivity reaches the highest echelons of the Department of Defense (DOD).

The main emphasis on increasing productivity can be summed up by a statement contained in the Air Force's Reliability and Maintainability program. "Air Force Logistics must shrink by design and direction in its consumption of total Air Force resources" (17). This policy guidance is the reason why we must seek higher productivity, but in order to do so we must understand what it means. Once done, the focus of discussion will shift to its application to Air Force (AF) transportation. In particular, the aspect of maximizing outputs with the minimal use of inputs will be keyed in on.

Increased Emphasis on Productivity Concepts

Productivity has been defined in terms of efficiency, effectiveness, or both. It has also been defined as the ratio of output to input for a particular activity (3:28). Additionally, this concept has been defined within the parameters of how well resources are brought together in organizations and utilized for accomplishing a set of results. Other conceptual definitions view it as reaching the highest level of performance with the least expenditure of resources (3:20). Finally, it has been defined as a combination of effectiveness and efficiency (3:27).

Effectiveness has been defined as "doing the right thing," and efficiency has been defined as "doing things right" (20). These terms have also been defined in terms of ratios. Efficiency is measured in terms of revenue divided expenses and effectiveness in terms of utilization, i.e., cargo capacity divided cargo hauled (2). These theoretical constructs provide a framework for the term productivity but how can it be applied to the DOD? This background will enable us to focus in on how the DOD perceives this issue.

Productivity in the DOD-- Definition and Implementation

The following words of Secretary of Defense Caspar Weinberger are more than a call to arms for DOD managers:

> I encourage every individual in the Defense community, both military and civilian, to look for opportunities to improve procedures, products, and effectiveness of his or her organization. By being innovative and creative and by aggressively pursuing goals of excellence and productivity, we can make significant gains in defense readiness. Equally important, those efforts will ensure full value from the funds entrusted to us by the American taxpayer. (4:27)

These words express the concerns of the highest level of management within the DOD. This concern is for increased productivity in the management of all DOD programs. One key program is the (AF) vehicle replacement program.

The AF vehicle replacement program involves the expenditure of hundreds of millions of dollars annually for the replacement of motor vehicles. This program is

used to replace vehicles that have exceeded their life expectancies, as well as, to fill open authorizations. This program's goal is to maintain the Air Force's vehicle fleet readiness in direct mission support, but for fiscal year 85 it sustained a $4.8 million reduction. The vast amount of resources involved in this replacement process in conjunction with severe funding cuts highlight the need to increase productivity. These cuts were independent of any action resulting from the Gramm-Rudman-Hollings Act. In the future the replacement program, henceforth known as the priority buy program, is expected to continue to experience reduction of funding in the years to come (30).

DODI 5010.34

Secretary Weinberger's words, went beyond demonstrating a need to do more with less, resulted in the development of DOD Initiative (DODI) 5010.34. This initiative defines productivity as "the ratio of goods produced or services rendered (outputs) to resources expended (inputs)" (3:36). This initiative went beyond the definable phase by establishing the basic objective of the DOD productivity program.

> The primary objective of the DOD productivity program is to achieve optimum productivity growth (increase the amounts of goods or services rendered in relation to the amount of resources expended) throughout the DOD. (5:9)

This objective has been applied in the way our AF bases manage their vehicle fleets.

AF Management of Vehicle Resources

The objectives of DODI 5010.34 are translated into action in the management of our AF vehicle fleets. Air Force Manual (AFM) 77-310 Volume I gives guidance on fleet operational management to the vehicle (operations) management branch, while Volume II directs the management of the vehicle maintenance branch. In AFM 77-310 Volume II guidance is given to the vehicle management (operations) officer (VOO) on how he/she should analyze and manage each wing's fleet. In AFM 77-310 Volume I, Chapter 3, paragraph 3-11 defines the role of one of the major subfunctions within the branch:

> The fleet analysis function is responsible for designing specific studies as requested by the VOO or fleet manager and for providing routine analysis required for evaluation of overall installation fleet performance, the appropriateness of authorizations and the effectiveness of the in-house vehicle fleet. (6:3.2)

Further guidance is given on general fleet (vehicle) analysis, authorization analysis and utilization information (6:3.2).

This requirement for the meticulous management of our vehicle fleet permeates throughout the vehicle function of a AF transportation squadron. AFM 77-310 Volume II, Chapter 2, outlines several management tasks of the vehicle maintenance branch. Within the maintenance branch it is the responsibility of the Maintenance Control and Analysis section (MCA) to monitor the progression of cost factors

for the wing's fleet. This is done through the compilation of a monthly digest. This digest uses certain performance factors as outlined in paragraph 2-21.

Management Indicators

To measure productivity, AF vehicle managers use indicators such as: (1) Labor Hour Utilization, (2) Vehicle Out of Commission (VOC) time to include Vehicles Down for Parts and Vehicles Down for Maintenance (VDM), (3) Cost, and (4) Preventative Maintenance (7:27). These standardized factors are analyzed and briefed to the base transportation officer on a monthly basis. The system used to track these costs on a monthly basis is the vehicle integrated management system (VIMS). Each month, as the vehicles accrue costs, the costs are tracked, stored (off computer runs placed in binders) and maintained in MCA. This data is usually stored for twelve months. As a new month passes by the last of the past twelve months data is discarded. There are several volumes of AFM 77-310 that contain the specifics of VIMS.

Vehicle Management Data

The data base is uploaded into the VIMS on a monthly basis. Each base, on a semiannual and an annual basis, inputs their VIMS data to the Warner Robins Air Logistics Center (WRALC). This data is then collated at the WRALC for Air Force-wide consolidation. The result

of these inputs is the Command Air Force Vehicle Integrated Management System (CAFVIMS). From the CAFVIMS an Air Force, as well as command-wide, vehicle management report is produced. This report tracks all vehicles and reports their average costs on a semiannual and annual basis. It keys in all the Air Force vehicles which are in one of several replacement codes.

Since January 1986 there has been an ongoing process to convert AF computer systems. The previous system, the Burroughs, is being replaced by the Sperry system. A direct result of this has been the loss of vehicle data (26). One major data base that has been dumped is the vehicle historical report. This report which is being rebuilt, stores vehicle data over time and is kept at the Warner Robins AFLC.

The Replacement Code System

The vehicle replacement code determines if a vehicle is eligible for inclusion in the priority buy program (8:5). The definition of, and progression through, the series of replacement codes is outlined in Air Force Technical Order (AFTO) 00-25-249 and AFTO 36A-1-1301. They are explained in detail in Appendices A and B. From the day a vehicle arrives at a base to the day it processes into salvage, it is in one of the replacement codes. The replacement codes are based on the straight-line method of vehicle depreciation. It is projected from its total life

expectancy. For example, upon arrival a sedan is in replacement code U (under warranty). Its AFTO life expectancy is 8 years and/or 72,000 miles. As it accrues miles and age, it transitions through the set of replacement codes. As the vehicle reaches its half-life, 4 years or 36,000 miles, it moves to replacement code R. As it reaches the 2-year point of its age or mileage limit, it moves to the N-Q replacement codes. This two-year out code is especially significant as it relates to the AF budget cycle. With the priority buy process, as well as the budget lead time, revolving around a two-year lead time, it (the two-year out code) plays a large role in the replacement process. As the vehicle reaches the last year of its life expectancy, 7 years or 54,000 miles, it is placed in the K-M replacement codes. Any additional age or miles accrued after its 8th year or 72,000 miles places it in one of the replacement codes A-J. It is at this point that the vehicle could be sent to salvage. From a practical perspective this does not happen as the vehicle may be in excellent condition or the base may be short authorizations. It is usually the latter, and the base involved may need to keep it until it is replaced. This critical concept, the use of replacement codes, is one of the key factors analyzed in the priority buy program. This discussion highlights the method of keeping track of the vehicle once it is in the fleet. The connection to

productivity in the DOD is a tieback to the earlier question raised: "Is there a way to increase our output (miles) with less input (dollars)?"

The manner in which these replacement codes are derived is unique to the Air Force only in its straight-line method of depreciation (8). The following procedures are the ones by which other organizations analyze the life cycle of a vehicle. The Australian Army uses a residual value approach in their scheme of replacing vehicles. The basic formula used is: $RV_n = C.A.B_n$ where RV represents residual value and n is the age of the vehicle, C is the purchase price, A is the immediate depreciated factor after purchase and B is the depreciated value of the vehicle at the end of each year (10:8.1). This comparison is made to show that, regardless of the method used, some basis exists for measuring the life cycle of vehicle assets.

The Phillips Petroleum Company, which has a vehicle fleet of 1500 passenger cars and 3800 trucks, uses a network model. This model, with its data base, are used to formulate replacement policies. These policies were enumerated in terms of replacement after "n months of service or m miles, whichever comes first" (31:2).

The model as represented by Figure 2, is set to minimize the discounted outgoing cash flow (DOCF).

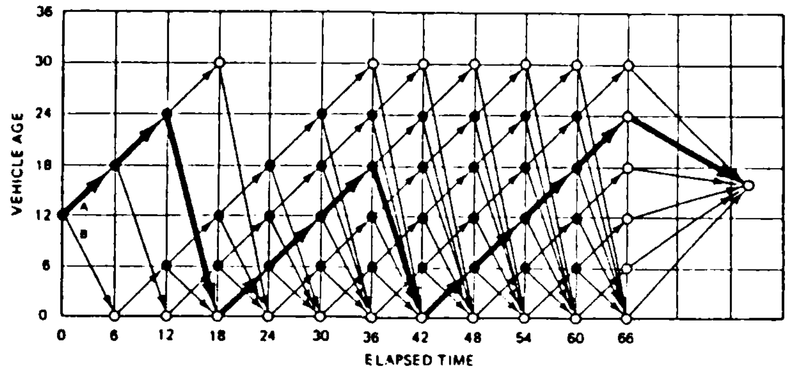

Figure 1 illustrates the model. The horizontal scale represents months into the activity and the vertical scale represents the age of the vehicle in months. Here opportunities for replacement occur every six months. The initial replacement decision is represented by the choices of transition A (retention) vs. transition B (replacement). If the bold path represents the minimum discounted outgoing cash flow (DOCF), then A (retention) would be recommended.

Fig. 2. Phillips Petroleum Replacement Model (31:350)

Operating and maintenance costs, i.e., fuel, oil, salaries, etc., make up the DOCF (31:2).

This demonstration, not only shows another potential use of models to the problem of vehicle allocation, but also clearly shows possible cost avoidance associated with a strategy of effective vehicle allocation. While certain factors do not directly bear on the DOD, i.e., discounts, cash flows, etc., in determining vehicle replacement codes, it does show another possible way that such codes could be developed.

In the Air Force the replacement code is used to establish the one-time repair limit (OTR). This limit is critical in that it allocates the amount of dollars that can be spent to repair a vehicle. It is one of the long-term systems costs mentioned earlier. This limit is based

on the following equation: (1.00 - (.9 X age or miles/ life expectancy in age or miles)) X the standard price (8:6). There are manual formulas for determining each. To determine the OTR based on age the formula is: age = the standard price X the years remaining divided by the life expectancy in years. The formula to determine the OTR based on mileage is: the standard price X remaining mileage divided by the life expectancy in miles (9:4-1). This formula for straight-line depreciation is used to aid in the decision to repair or not to repair a vehicle. The one-time repair decision strongly influences the priority buy program; however, the priority buy program is primarily designed to fill open authorizations (8:5). The objective of the priority buy program has also been viewed from another perspective. This perspective views it as being a program that replaces eligible vehicles and fills open authorizations. These functions are viewed with equal weights (12).

Table 2 represents the life cycles, in age and miles, of some general purpose vehicles. It also shows the one-time repair. It is represented by the percentage row. This percentage is the amount that can be spent to repair the vehicle. It is directly relative to the standard price. The standard price, which is on the vehicle master list, is normally the purchase price associated with the vehicle. For example, if the standard price

TABLE 2

MAXIMUM ONE-TIME REPAIR ALLOWANCE (25:20)

General Purpose Vehicles Vehicle Type	Life Expectancy Yrs/Miles		Years									
			1	2	3	4	5	6	7	8	9	10
Amb, Metro & Van	8/60	Miles	8	15	23	30	38	45	53	60		
		Percent	88	75	63	50	38	25	13	10		
Sedans	8/72	Miles	9	18	27	36	45	54	63	72		
		Percent	88	75	63	50	38	25	13	10		
Station Wagons	8/72	Miles	9	18	27	36	45	54	63	72		
		Percent	88	75	63	50	38	25	13	10		
Bus-12 Pax	8/84	Miles	11	21	32	42	53	63	74	84		
		Percent	88	75	63	50	38	25	13	10		
Bus-19-37 Pax	9/84	Miles	9	19	28	37	47	56	65	75	84	
		Percent	89	78	67	56	44	33	22	11	10	
Bus-Over 37 Pax	10/100	Miles	10	20	30	40	50	60	70	80	90	100
		Percent	90	80	70	60	50	40	30	20	10	10

NOTE: All mileage is expressed in tousands.

of a bus is $35,000, and its life expectancy is 100,000 miles and/or 10 years, then in the first year 90 percent of the standard price can be spent to repair it. This OTR limit is set to decrease over time. As in the example mentioned above the OTR will continue to decrease at a straight-line rate.

The key to the OTR is that it is constrained by a time-phased percentage. This time-phased percentage is demonstrated in Table 2. It is the limitation to the amount of maintenance dollars that can be spent. Once a vehicle reaches its out years or mileage limits, it can normally have up to 10 percent of its standard price for allowable maintenance. The 10 percent limit is the lowest that normally can be expended; however, the Deputy Commander for Resource Management (DCR) can authorize minor deviations to this rule. The DCR can further delegate this waiver authority to the vehicle maintenance officer.

Vehicle Acquisition Process

Now having established some parameters for the replacement of vehicles, it is time to address an even more basic question. How are Air Force vehicles acquired? The question is simple; it is the process that is complex. Each vehicle type is broken down by function, and an allowance is established based on that function. This consolidated list of functions and allowances is contained in the Table of Allowances 010 (TA). For example, if there

is an aerial port squadron with an air terminal operations center, the TA will show that a truck is allowed to perform that function, i.e., flight line operation supervision. It then gives the national stock number for that truck (11). The TA is the major source of vehicle allowances, but merely sets allowances and does not in itself authorize anything. The TA is the basic starting place in the quest for a vehicle. The next step in this process involves accounting for, and justifying, vehicles needed to perform the unit's basic mission or any significant mission changes.

This process is made up of two major components. The first component is the priority buy process. This process is the tool used which attempts to fund for the replacement of vehicles. The second component details accounting for and making vehicle authorization changes based on mission requirements. The first builds off the second, and both are started at the base level. While the request for change to a vehicle fleet, through the Air Force 601 process, seeks to make a change to the TA, it is the priority buy program which actually funds for the vehicle assets.

The Priority Buy Process

The procedures necessary to fill basic requirements, replace vehicles that have outlived their life expectancies, is outlined in AFTO 00-25-249. This AFTO currently

guides base level managers in preparing their priority buy submissions (12:1). Requirements for the next two years are formulated at the base level vehicle management branch and submitted for approval to the base/wing Vehicle Authorization Utilization Board (VAUB). Again, this process emphasizes the budget cycle and why we meticulously monitor vehicles as they reach the two-year out point in their life cycle. This board, chaired by the Deputy Commander for Resource Management (DCR), reviews and approves the buy submission and then forwards it to MAJCOM/LGTV.

The MAJCOM/LGTV reviews the base's inputs and submits a consolidated buy submission. This submission is done by the vehicle management specialists at MAJCOM who review all base inputs and data stored in supply's Registered Equipment Management System (REMS). This command buy program is forwarded to the Directorate of Material Management Vehicles Division (MMV) at WRALC. There are five priorities, each broken down in columns of 20 percent. Each column total requested by each priority is restricted to 20 percent of the total requested. So, for example, priority one would be no more than 20 percent; priority two, 20 percent (40 percent of the total); priority 3, 20 percent (60 percent of the total); priorities 4 and 5 make up the rest of the package. These priorities, and the

determination of which vehicles are placed in each category, are essential to the program.

The following highlights the importance of the designation of priorities:

> The system recognizes that not all of the requested funds will be allocated, but if only twenty percent of the requested budget is approved, MMV would be able to look at the command priority list and provide most of the vehicles that were identified as the most critical for replacement. (25:21)

Additionally, each MAJCOM can anticipate getting almost all of their priority 1 and a significant number of their priority 2 requests (13). The MAJCOM currently use the fair share approach in the management of their base's fleets. A key point in this system is that while MAJCOMs attempt to keep the vehicle fleets equitable, sudden mission changes can affect the way vehicles are allocated. Another key point is the command's use of the priority buy process as the instrument to maintain the balance of their fleets. The priority buy process is one that is not so much constrained by the number of vehicles that can be bought, but by the dollars available within the funding cycle. It was designed with one key assumption in mind. The assumption is that the program would be built around full funding (12).

Each command submits its priority buy package to WRALC/MMV. MMV then coordinates the final buy list with Headquarters, Air Force Logistics Command (HQ AFLC) and Headquarters, United States Air Force (HQ USAF) (27:35).

MMV is the center of the priority buy process (27:32). It is the nerve center which coordinates all of the command's buy packages into the AF priority buy package. This coordination is done during the semiannual vehicle requirements review at WRALC. This review is done to finalize the numbers and types of vehicles to be purchased by the Air Force. This review is done through the priority buy review panel.

The priority buy review panel is made of representatives of HQ USAF, HQ AFLC and MMV/WRALC. This panel decides on the number and the types of vehicles to be bought based on the budget estimate submission (BES). This means that if there were 800 station wagons on the AF priority one category, but only 80 percent funding, then only 640 will be purchased (24). This process basically matches up projected available dollars against vehicle requirements. It sets the bottom-line dollar to vehicle ratio (24).

This process, while restrained by funding levels, allows for allocation flexibility. The item manager for vehicles, located within the MMV, will contact the MAJCOM/LGT as to the reduction and ask for shipping instructions (24). This is how the priority buy dollars become assets. This emphasizes the need for the devlelopment of a model which can assist the MAJCOM/LGT make this critical allocation decision.

As mentioned earlier, funding is normally available for almost all of the priority 1 and 2 requests. Once the funding levels and the corresponding number of vehicles to be purchased have been established the MAJCOM/LGT is notified of the decision. It is the MAJCOM/LGT that directs WRALC/MMV, by providing the shipping instructions, where to ship the assets. Table 3 summarizes the relationships between the major players involved in this process.

Base Level Process

The following highlights the priority buy program as it was done at the 401st Transportation Squadron, Spain, from February 1983 to May 1985. In February 1983 and February 1985 the buy programs for FY 84/85 and FY 86/87 were submitted. The fleet analysis section gathered data from base units, the myriad maintenance management reports and drafted the initial package. The Vehicle Management Officer then reviewed their reports and prepared the final draft version of the AFTO Form 468 for the VAUB. The VAUB also acts as an adjuster in its quarterly meetings which reviews requests for new authorizations. In reviewing requests for any change in vehicle authorization, the VAUB will query the VOO as to how the base's vehicle fleet compares to the TA. Then the VAUB reviews and recommends approval or disapproval for any new requests. Once local VAUB action is complete, all new authorizations are

TABLE 3

SUMMARY OF VEHICLE RESPONSIBILITIES AT EACH LEVEL OF MANAGEMENT (25:16)

Base	MAJCOM	WRALC (MMV)	HQ AFLC	HQ USAF
Performs maintenance	Consolidates replacement codes	Consolidates replacement codes	Approves final buy programs	Provides general guidance
Operates vehicles	Coordinates overhaul actions	Determines buy requirements		Liaison with Congress monitors
Maintains vehicle records	Maintains command authorized list	Prepares PRs on buy	Coordinates/ approves vehicle budget	
Updates replacement codes	Distributes new assets among bases	Distributes new assets among commands	Monitors MMV actions (on a staff basis only)	Congressional compliance requirements Defends vehicle budget

forwarded to MAJCOM for final action. The results of these procedings are tracked through two AF forms. The first, AF Form 1374, is the form requesting a change be made to the unit's vehicle authorization. The second, AF Form 601, is a supply form that requests a change be made to the TA. This function allows for changes in mission requirements and keeps senior wing management appraised of the status of the wing's fleet. While the goal of the MAJCOM/LGT was to attempt a balance of base fleets, the dollar constraints imposed on the priority buy program oftentimes precluded this from occurring.

Modeling Attempt

This is the current system and although it appears sound and feasible, is it the best way? Does this way get the job done (outputs) with the most efficient use of resources (inputs)? This question was addressed in the early 1970s because of the massive budget cuts imposed on the procurement of Air Force vehicles. In an effort to effectively use inputs, the Air Force, through the Study to Automate Logistics (STALOG) office, contracted with the Federal Simulation Center (FEDSIM) for the development of "The Air Force Vehicle Replacement Model" (12:ii). Although this model was too inflexible to meet Air Force requirements, it served as an attempt to get more outputs (vehicle road time) for less inputs (resources). The

FEDSIM vehicle replacement model had three major deficiencies. They were:

> . . .1) the current priority buy report provides no new information to which the vehicle manager does not already have access, 2) the model provides no new information to which the vehicle manager does not already have access, and 3) the trends and analysis data produced were weak and should not be the basis of management decisions. (12:20)

It further has the problem of not being able to deal with small sample sizes (12).

This attempt to use modeling to direct the allocation of vehicles failed to replace the existing priority buy program. It could not accurately assess the myriad of outside variables which impact AF transportation squadrons. It did open up a new avenue for further research. Such research was done using linear programming in assisting allocation decisions made by North American Van Lines, Inc. (15:1). The point to be made does not focus on the specifics of the model, but that the model was used to complement management in making the optimal allocation decisions. Another successful approach using modeling was done by an English firm in projecting forklift maintenance costs. It involved the Bayesian approach to equipment replacement (16:33).

The problem involved in reviewing these models is that they use profit variables. As a not-for-profit organization, the DOD cannot address certain variables. In the North American Van Lines application, such variables

as trade-in value and direct salvage value were addressed. While salvage value on AF vehicles is a relative variable, it is not handled the same way in the corporate world. In the corporate sector, trade-in value is applied directly against the purchase of a new vehicle. The DOD, on the other hand, receives whatever the market will bear when a vehicle is sold at salvage, only after a myriad of other federal, state, local, and charitable organizations are offered an opportunity to withdraw the asset for no charge (12).

Modeling Development

The main emphasis of this thesis is using a model to assist in the allocation of general purpose vehicles. Why use a model? "Because models are representations of real objectives or situations" (19:4). Although models cannot totally represent reality, they can give the manager a close representation. This representation can effectively assist him in making that crucial allocation decision. The use of this tool in conjunction with the current management systems will increase the decision maker's productivity.

In the example where the Bayesian model was applied to forklifts, there were certain variables used that do not apply to the DOD. The DOD does not receive cash in-flows for the usage of AF vehicles. Trade-in values and after-tax cash outflows are not of concern to the DOD. Although these unique variables do not directly impact the realm of

AF transportation, they served as the basis from which the following regression model was developed. From the Bayesian article, there was a smaller suggestion of a straight-line relationship used to predict costs of a truck: "We shall assume that at any age x, a truck incurs a normally distributed maintenance cost whose expected value is a linear function of age" (16:34). Thus, $Y = \beta_1 + \beta_2 X + e$ where Y is the maintenance cost during the year; X is the age of the truck; the Beta coefficients are unknown maintenance parameters; and the error term (e) is a normally distributed variable with zero mean and variance (16:34).

Regression, in the vehicle allocation environment, was used by the Seattle Metro Transit Authority, The particular application of regression in this case was to develop an optimum replacement age for Transit buses. The key question under study was "to replace or not to replace?" This question, vehicle replacement versus continued operation, has traditionally been answered by the decision maker's "gut feeling" (21:41).

The first step in the development of the basic regression equation used in this approach was the establishment of several linear relationships. The first of these relationships derived cost as a function of age. Once this relationship was confirmed, the following basic equation was presented: maintenance and repair cost (M&R) = $\beta_0 + \beta_1(N)$

where N equals vehicle age (21:43). Several other equations were formulated from this basic equation. They were: total cost; downtime; and operating costs. The development of these equations included another variable into the model. This variable was vehicle mileage and was shown in the equation for total cost. The following represents this model: total cost TC = $(\beta_0 + \beta_1 (N))(M)$ (down[illegible] 1000 where M equals mileage and 1000 equals thousands of miles of annual output (21:44).

Another approach to vehicle replacement, used by the British Gas Corporation, is the net present value (NPV) model. The British Gas Corporation has a vehicle fleet size comprised of some 22,000 commercial vehicles and 2,000 cars (33:899). The NPV model is represented by the following:

V_3 = NPV of the first cycle X [1 + (1/1 +10/100)3
+ 1/ (1+10/100)6 + ...]
= NPV of the first cycle X 1/1 - (100/110)3
(33:901)

This NPV is determined for both a new vehicle and for keeping a current vehicle. It is then further developed to:

average discounted cost (AADC)n = the sum of k=0 of
n C_k/ (1+r)k = NPV of the first cycle, where
C_k is the cash flow in the year k of the cycle
(33:901)

This can be verbally expressed as:

AADCn = Sum of the present values of the cash flows/ Sum of the discount factors (33:901)

This different approach again highlights the potential for model employment in the process of vehicle allocation. It is graphically demonstrated in Figure 3.

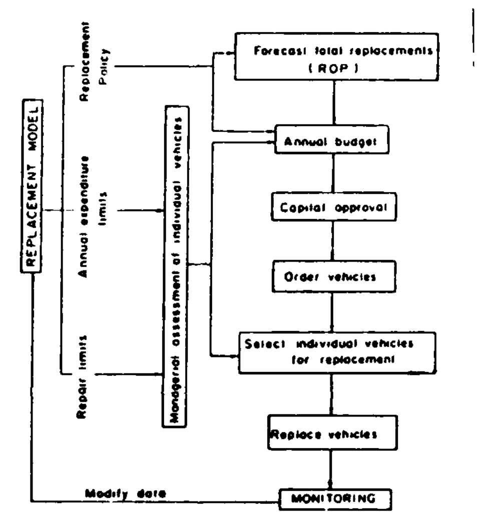

Fig. 3. Model Employment (33:906)

<u>Model Introduction</u>

From the basic regression models mentioned above the following model as used in this thesis, was developed: Y (predicted maintenance cost) = $\beta_0 + \beta_1 X_1 + \beta_2 X_2$ where X_1 equals age and X_2 equals average miles per year. Once the regression model is run, a command function (standard) will be established. Then each base within the sample will be compared to the command function (standard). The point

of this comparison is to see which bases are above and are below the command standard.

This measurement will indicate to the MAJCOM/LGT which bases may have either controllable or uncontrollable factors contributing to its position. This indicator can assist the decision maker in reviewing his fleet costs. It can also be used to see if a more effective placement of general purpose vehicles can be done using a strategy of placing vehicles where they will reduce his overall fleet costs. It is designed to be another tool that the MAJCOM/LGT will have access to in making his allocation decision. After all, they will be the ones with the knowledge of their transportation squadron's overall requirements.

This model will allow a second look using a predicted cost based on age and annual average mileage to place the next unit where it will decrease the overall fleet cost. Unlike the FEDSIM model this model allows the MAJCOM/LGT the flexibility to ultimately place the vehicle where he sees the greatest need. It will give them a chance to glance over the cost tangent and either use it in part or completely when making their decisions. Arrangements have been made with the bases within AFSC as to the availability of the data. There was a problem in getting the individual data from the AFSC bases. Only

three of the AFSC bases were able to deliver the requested data.

Summary

This literature review has discussed the following topics. It started off by providing a historical perspective of vehicle acquisition. The next area of discussion was the current philosophy behind the priority buy program. Following this discussion was an environment analysis. It then focused in on the concept of productivity, its application to the DOD and to AF transportation. It went from general definitions of productivity to ones emphasized by the DOD. Once defined, it was shown how productivity is demonstrated in the day-to-day operations of AF vehicle fleets. Following a brief overview of the daily management of AF vehicle functions, a discussion was presented on the current system of allocating vehicles. Finally, the potential for and the development of models for use in the allocation of vehicles was presented. This culminated in the introduction of the linear regression model used in this thesis.

III. Methodology

Introduction

This chapter presents a detailed explanation of the methodology used in this thesis. First, the steps which resulted in the selection of the data base are explained. Next the data collected for analysis are presented. This presentation includes the collection procedures and an explanation of the variables used. Following this, the rationale behind the use of regression analysis is presented. The basic assumptions of regression will be included in this explanation as well as the statistical procedures used to validate the model.

Once the initial parameters of the study are clearly established, the model will be reintroduced. The analysis begins by establishing the validity of the regression model selected. Next, the assumptions of the model are stipulated. This portion of the chapter facilitates additional usage of this model for follow-on research.

This chapter concludes with a section of data used in this research effort. This section addresses the basic data and the procedures used to process the data into the AFIT computer system. Lastly, problems and constraints surrounding the data base will be addressed. This discussion will proceed to the details behind the data base.

The data base used in this study was obtained, with the assistance of the Director of Transportation, Headquarters Air Force Systems Command (HQ AFSC/LGT), from Air Force Systems Command (AFSC) bases. The source for the data base consisted of 12 months of Vehicle Management Reports (PCN 32). Initially all bases within the Systems Command were to be included in this study; however, due to outside factors, only Hanscom and Patrick supplied the necessary data. From the Vehicle Management Reports (PCN 32) the following data was transcribed to the AFIT computer system: past total maintenance cost, mileage, vehicle type, age, and management code.

This data approach was used because it provided an accurate way to compare maintenance costs between the bases within the command. Initial attempts were taken to review the CAFVIMS data for Systems Command; however, the aggregate nature that data did not meet the requirements of this thesis. This is to say that there is no way to compare bases using this data base. The aggregate nature of the CAFVIMS data does not allow comparisons between bases. This is because of the way the data is reported in the CAFVIMS data base, i.e., the data are sorted by replacement code and consolidated in an aggregate fashion.

Variable Selection

Two different types of variables were used in the model--the dependent variables, the ones to be predicted,

and the independent variables. The independent variables are used to predict the dependent variable. The single dependent variable for this study was total vehicle maintenance cost. The independent variables for this thesis were age and annual average miles driven. These independent variables were chosen based on the results of stepwise regression analysis. This analysis, as outlined later in this chapter, tested all variables selected for the model. These independent variables, based on the SAS stepwise function criteria, were the ones that formed the model. The SAS stepwise regression function tested each variable's t test and F values. Only the variables and their model with both a statistically significant F value and individual Beta coefficient t-test values were allowed to remain in the stepwise model. The results presented in Chapter IV pertain only to the variables and the model selected through the SAS stepwise function.

The dependent variable was maintenance cost. The vehicle maintenance cost is the total direct and indirect labor and materials used on each vehicle for each month. It was taken from the PCN 32. This variable was the key variable because it provided an estimate of future maintenance costs for the bases in the study. As such, it played a key role in estimating the future value of each O&M dollar spent for vehicle maintenance. The O&M dollar values are specified and compared in the next chapter.

They are one indicator that the MAJCOM/LGT can use in comparing the maintenance cost between subordinate bases. These variables, or derivatives thereof, had previously been addressed in some of the literature reviewed for this thesis. It was the selection and usage of these variables that allowed for the successful development and implementation of this model. The discussion now shifts to the tenets pertaining to regression.

Regression--Basic Concepts

Within the realm of cost estimation a major method used is the parametric or cost-estimating relationship (CER) (35:65). The CER approach is one that attempts to model a predicted cost using the least squares method of regression analysis (35:66).

Regression was chosen as the quantitative method for this study because of its ability to predict the value of one variable based on the values of other linearly related variables. Regression analysis has been defined as "a statistical tool which utilizes the relation between two or more quantitative variables so that one variable can be predicted from the other, or others" (36:21).

Specifically, the value to be predicted, based on the input of past PCN 32 data, was the maintenance cost at base X. The power of this tool is derived from its ability to show certain aspects and relationships of the variables in the model. As detailed later in this chapter, regression

acts upon the basis of setting the best fit between the dependent and independent variables (35:456).

For example, it can show if the variables are interrelated and if they contribute information about each other (36:395). The effect of each independent variable has on predicting the dependent variable can be demonstrated by testing the Beta coefficients which are the solution values of the specific regression problem. A t-test is used to determine if each of these coefficients contributes significantly to predicting the dependent variable. This statistical method can also consider relating the mean value of a dependent variable, in this case maintenance cost, to the independent variables using a linear relationship (36:395).

Another reason that regression was used is that the variables selected to be studied have, as seen in the literature review, suggested to have a linear relationship. Similar types of regression analysis were reported by Armour (21) and Taylor (16). Their analysis pertained to similar type variables and data. While these authors did not present their R^2 values, their research suggested a linear relationship of miles and age to cost.

As mentioned in Chapter II, Taylor took the Bayesian approach to predict maintenance costs of a small fleet of trucks. Based on his data the following model was used:

$Y = \beta_1 + \beta_2 X_1 + e$ where Y is the maintenance cost during the age of the truck; X is the age of the truck and Beta coefficients are unknown maintenance parameters and e represents the error term with its critical assumptions (16:34).

Armour analyzed fleet data from the Seattle Metro Mass Transit fleet. After determining that the data was conducive to regression analysis, he determined the following:

TC (total cost) = $(\beta_0 + \beta_1(N))$ (M) (downtime)/1000 where N equals vehicle age; M equals mileage and 1000 equals thousands of miles of annual output (21:44).

Their suggested potential for regression applications were different. One applied to forklifts and trucks while the other applied to transit buses. These studies provided a conceptual basis for the application of linear regression to this problem.

It will also be shown, through statistical tests for significance and attached figures, that this model is effective in its attempt to predict maintenance costs based on vehicle age and mileage. This effort seeks to develop and implement a tool which draws its statistical power from historical data. "Historical costs probably provide the basis for determining what future costs will be" (21:30). The cost data, in conjunction with the mileage data, from

the bases provide the necessary data base to conduct the regression analysis.

Having shown why regression was chosen, the discussion now shifts to regression models and their uses. The following points show how a regression model can portray the two key ingredients of a statistical relationship:

1. The tendency of the dependent variable (Y) to vary with the independent variables (regressors) in a systematic fashion.

2. It will show the scattering of observations around the curve of the statistical relationship (36:25). As it applies to the variables used in this thesis, the relationship between the independent and dependent variables once established demonstrates the effectiveness of the statistical relationship.

These two characteristics are embodied in a regression model by using the following tenets:

1. Within the populations associated with the observations of X and Y there is a probability distribution of Y for each level of X.

2. The means of these probability distributions vary in some degree with X (36:26).

These basic concepts give further credence to the use of regression, the basic quantitative tool, for this particular study.

Reintroduction of the Regression Model

The basic format of the model is $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + e$ where Y = the dependent variable, the one to be predicted (in this case the predicted maintenance cost); e = the error component; β_0 = the Y intercept; β's = the slopes of lines (36:397). The independent variables in this model are: X_1 age and X_2 average miles per year.

When using this technique one of the most important assumptions which relates to the error probability distribution is:

> 1) The mean of the probability distribution of e is zero; 2) The variance of the probability distribution of e is constant for all settings of the independent variable X; 3) The probability distribution of e is normal; and 4) The errors established with any two different observations are independent. (36:408)

The assumptions of the error term in relation to the model will be domonstrated in a series of residual charts. These residual charts are presented in Chapter IV.

Regression--Basic Functions

Regression analysis can be used to describe, to control, and/or predict (36:30). These functions can be overlapping and of major assistance to management. The purpose of this study is to predict future maintenance costs at five bases with AF Systems Command. The results can show which of the bases is likely to experience the highest vehicle maintenance costs.

From the results of the regression analysis, the MAJCOM/LGT can determine if there is major variance between the subordinate bases. If significant variance is present, the MAJCOM/LGT can investigate causal factors and act accordingly. The MAJCOM/LGT can also use these results in assisting him in the allocation of new assets. This distribution, through the priority buy program, can be made as to reduce the overall maintenance cost to the AFSC fleet. Having addressed the basics of regression and its implications for use, the basic statistical concepts used are presented.

Regression--Technical and Statistical Aspects

The primary method to measure the contribution of x in predicting y is to consider the coefficient of determination. The coefficient of determination will consider how much the errors of prediction of Y were reduced by using the information provided by X (35:421). The coefficient of determination (r^2) is technically defined as

> . . . the square of the coefficient of correlation. It represents the proportion of the sum of squares of deviations of the Y values about their predicted values that can be attributed to a linear relation between Y and X. (35:423)

The r^2 always has a numerical value of between 0 and 1. An r^2 value of .60, for example, would mean that the sum of squares of deviations of the Y values about their predicted values has been reduced by 60 percent by the use of

the least squares equation y (hat-fitted (predicted) values of y) instead of y (bar-the mean of y) to predict Y. What this is saying is that while a sample mean of y can be used to make predictions about y, in this particular method it is better to use the fitted values of y. This relates back to the r^2 value of .60 in that it is 60 percent better as a predictor than if the mean values of y had been used to predict Y. This is done through the use of a least squares line (35:424). Figure 4 demonstrates this tenet.

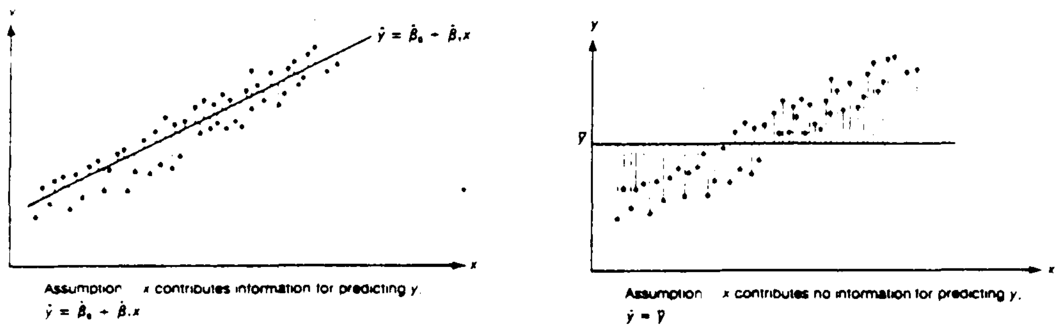

Fig. 4. Basic Demonstration of Regression

Statistical Tests

The following statistical tests were used to validate the model: t-test; F-test; Durbin-Watson test; and the Cook's D test. Each of these tests will be fully explained in the subsequent paragraphs. Before explaining these tests, the following steps in developing the multiple regression model are set forth:

1. Hypothesize the form of the model, in this case it is Y (predicted maintenance cost) = $\beta_0 + \beta_1 X_1 + \beta_2 X_2 + e$. Where X_1 and X_2 are identified as age and average miles per year, respectively.

2. The second procedure involved is estimating the β (Beta) parameters, again β_0, β_1, and β_2 are the ones for this model.

3. Testing the key assumptions of the e probability distribution.

4. Check the utility of the model through the use of the above mentioned statistical tests.

5. Lastly, use the fitted model to predict a value of Y using the values of the independent variables (X_1 and X_2) (35:465).

To test the individual parameter (β coefficient) in a multiple regression model a t-test is used. The format of this test is represented by the following:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_k X_k + e$

H_o: $\beta_i = 0$

H_a: β_i does not = 0

test statistic is $t = \beta/S\beta_i$

rejection region: $t > t$ alpha/2

where

n = number of observations

k = number of independent observations in the model

and t alpha/2 is based on [n-(k+1)] degrees of freedom (35:360).

While this test measures the individual parameter coefficient's value and worth in the model, the F test is used to validate the complete model. The F test is represented by the following:

test statistic $F = R^2 / k / (1-R^2) / [n-(k+1)]$

where

R^2 = coefficient of determination

n = number of observations

k = number of independent variables in the model (35:9)

Rejection region: $F > F$ alpha where $v_1 = k$ df (degrees of freedom), $v_2 = n - (k+1)$df

where

$H_o = \beta_1 = \beta_2 = 0$

H_a = at least one of the two model coefficients is nonzero (35:475).

Since the data used in this study was collected over 12 months, the next test is especially relevant. The Durbin-Watson test, under the assumptions of linear regression, seeks to test whether or not the error terms are uncorrelated. The usual alternatives of this test are expressed as the following:

C_1: $p = 0$ (no autocorrelation)

C_2: $p > 0$ (positive autocorrelated)

The decision rule for deciding which of these alternatives prevails is:

If $D > d_u$ (the upper limit of the d table), conclude C_1

If $D < d_l$ (the lower limit of the d table), conclude C_2

If $d_l < D < d_u$ (or equal to either), the test is inconclusive (36:358).

While the next measure is not a specialized test, it screens for multicollinearity. The tolerance for each β coefficient is the indicator for this condition. If the tolerance is less than or equal to .1 or .2, then there is an indication of multicollinearity (39). Multicollinearity is a condition where the independent variables are correlated among themselves (36:250).

The last major statistical test to be used is the Cook's D distance. This test is a measure of the ith observation on the estimated regression coefficients. If the percentile value of the residual is between 10 and 20 percent, it (alone) has no significant bearing on the model (37:408). On the other hand, if it falls within 50 percent or more it should be carefully reviewed to see if it (the observation) may be an outlier. These statistical tests are included in the SAS software package used in this thesis.

Before going into an in-depth explanation of the procedures used in the collection and processing of the data, a brief explanation will be given on the SAS software package. The SAS system is a software program for data analysis (37). The statistical procedures in the SAS package are designed for several types of statistical analysis. The following analysis packages used in this thesis were regression and stepwise regression.

The SAS software package is stored on the classroom support computer (CSC) located at the Air Force Institute of Technology. It was selected as the statistical package for this thesis because of its availability and capability. The capability of SAS to do the required regression runs facilitated the development of the model. The focus of this discussion will now shift to the details of the SAS stepwise regression procedures.

The PROC STEPWISE procedure is summed up in the following:

> The stepwise method is a modification of the forward selection technique and differs in that variables already in the model do not necessarily stay there. As in the forward-selection method variables are added one by one to the model, and the F statistic for a variable to be added must be significant at the SLENTRY=level. After a variable is added, however, the stepwise method looks at all the variables in the model already included in the model and deletes any variable that does not produce an F statistic significant at the SLSTAY=level. (38:764)

This approach confronts the most difficult problem of model building. The problem is deciding which of the

independent variables to include in the model. This systematic approach of screening the model through its various steps, through the use of the F statistic, is known as stepwise regression (35:570). This basically concludes this section on the statistical procedures used.

The next section will describe the data used. The initial concept was to collect twelve months of data from each AFSC base. This data was to be in the form of the PCN 32 reports, parts 5A and 5B. Once this data arrived, it was painstakingly reviewed to ensure there were no gross errors. It was manually transcribed into the AFIT computer system through a CSC data file. Then the completed data sets would be used in the SAS software package.

This plan ran into some problems. Due to time constraints and computer problems, only two of the bases were able to respond. Thus, two bases will make up a consolidated model. This hypothetical situation will demonstrate a composite of a model designed to show the command (AFSC).

Another problem concerned the data itself. There were entries that appeared to be totally unreasonable, e.g., a vehicle traveling 60,816 miles in one month. To counter this problem other data for like vehicle types was carefully analyzed and adjusted accordingly.

After the model was run, the results were applied to these two bases as if they represented the entire

command. The point is that this model, although limited by data input, can be applied to any command.

Summary

This chapter began by introducing the environment surrounding the data base. Next, a basic discussion of linear regression was presented. This presentation reintroduced the model used in this research effort and justified its selection as the primary tool in this study. The chapter also described the statistical test used to verify the significance of the model, the statistical software package, and the data base.

IV. Analysis

Introduction

This chapter presents a brief synopsis of the model and the way it was developed. Next, an analysis of the model, for the bases involved, is presented. The two bases involved, Hanscom and Patrick, provided 12 months of PCN 32 reports. An examination of these results will focus around the model and the particular statistical tests mentioned in Chapter III. Following this analysis each of the investigative questions presented in Chapter I is addressed.

The data base from Hanscom was received first, and, as such, was the first to be run through the SAS software. The results of the PROC STEPWISE procedure led to the following:

$$Y \text{ (predicted maintenance cost)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

where

X_1 equals age, and X_2 equals average miles.

The first result to be reviewed pertained to the assumptions of the error term (e). Figure 5, student residuals by the residuals, displays a horn shape. If the data met the assumption for equal variance (homoscedasticity) for e, then there would be a random scattering of points. There is a definite horn shape in this figure. This particulat shape indicates the error variance is not equal. It

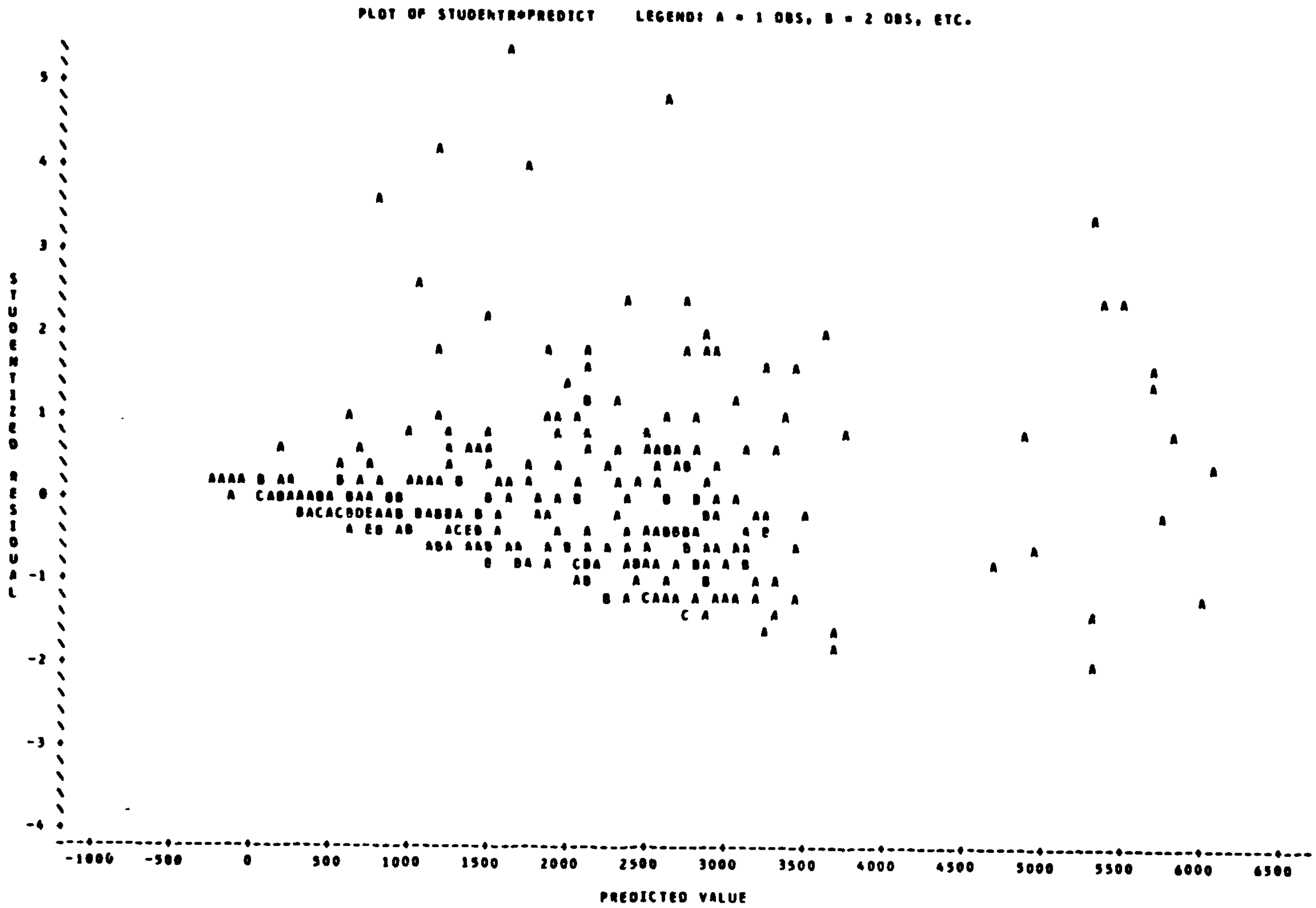

Fig. 5. Residual Variance (Untransformed) for Base 1

demonstrates that variance increases with X_1 and X_2 (36:101). This highlights the requirement for transformation of the dependent variable. This increase in the variance detracts the model's predictive ability. As it cannot be determined whether or not the ability to predict the dependent variable is a direct function of the regressors (X_1 and X_2).

One method used to correct the problem with unequal variance is to transform the dependent variable (36:127). In this case, the square root transformation was used on the dependent variable. This process involved taking the square root of the dependent variable versus using the variable direct. The results of this action can be seen in Figure 6. There is no real distinctive shape per se and the figure now clearly indicates a random scattering of points. This indicates that the assumption of constant variance of e has been met.

The next critical assumption of e is the one concerning the probability distribution of e. The test for whether or not the probability distribution of e is normal or not was conducted by using a SAS procedure known as PROC RANK. This procedure, through its use of an internal normal statistic (normal=blom) (39:649), ranked the residuals and then tested the obtained residuals against the ranked ones.

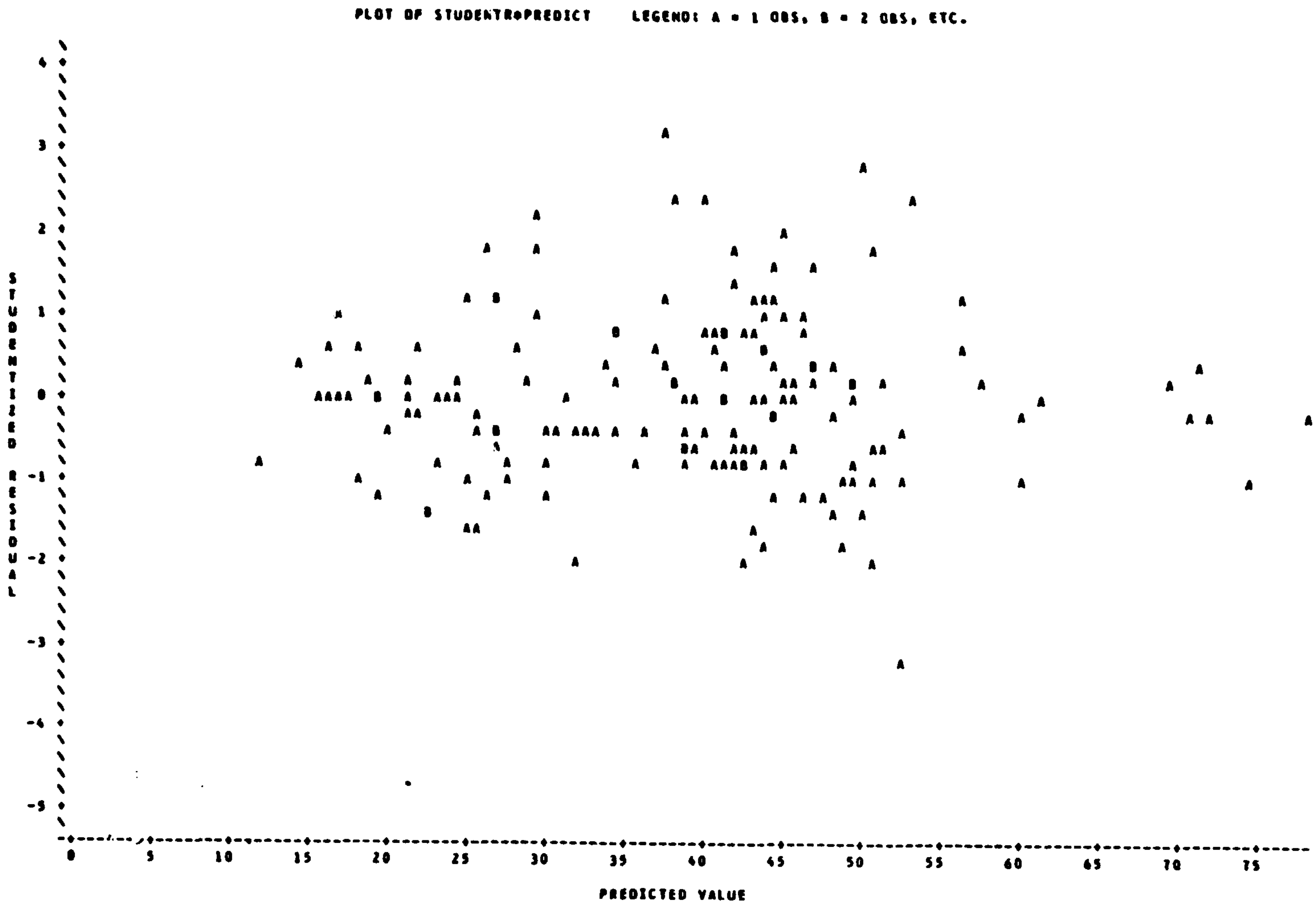

Fig. 6. Residual Variance (Transformed) for Base 1

Figure 7 is nonlinear and, as such, indicates the existence of an other than normal probability distribution. The transformation of the dependent variable, using the square root of the dependent variable, seems to correct this problem. Figure 8 shows the resulting linear relationship. This establishes the two major assumptions of the e term. The third, the mean of the probability is zero, is assumed based on the verification of the other two assumptions of the e terms.

For base 1, Hanscom, the following regression equation was produced from the SAS software.

$$Y \text{ (predicted maintenance cost)} = 9.43 + 2.98\, X_1 + .0016\, X_2$$

where X_1 = age and X_2 = average miles.

Statistical Tests of the Model

For the statistical tests mentioned earlier, the significance level chosen was .05. This means that there is a 95 percent chance of the results being correct. The F value for the complete model was 49.71. This F value indicates that the model is a valid one to use. The t tests of the individual Beta coefficients, $\beta_0 = 2.94$, $\beta_1 = 7.63$, and $\beta_2 = 7.11$, show that each one contributes to predicting Y. The Durbin Watson statistic is inconclusive. Its value of 1.57 leaned towards showing no autocorrelation. The tolerance of .99 indicates no multicollinearity, and the Cook's D showed no outliers.

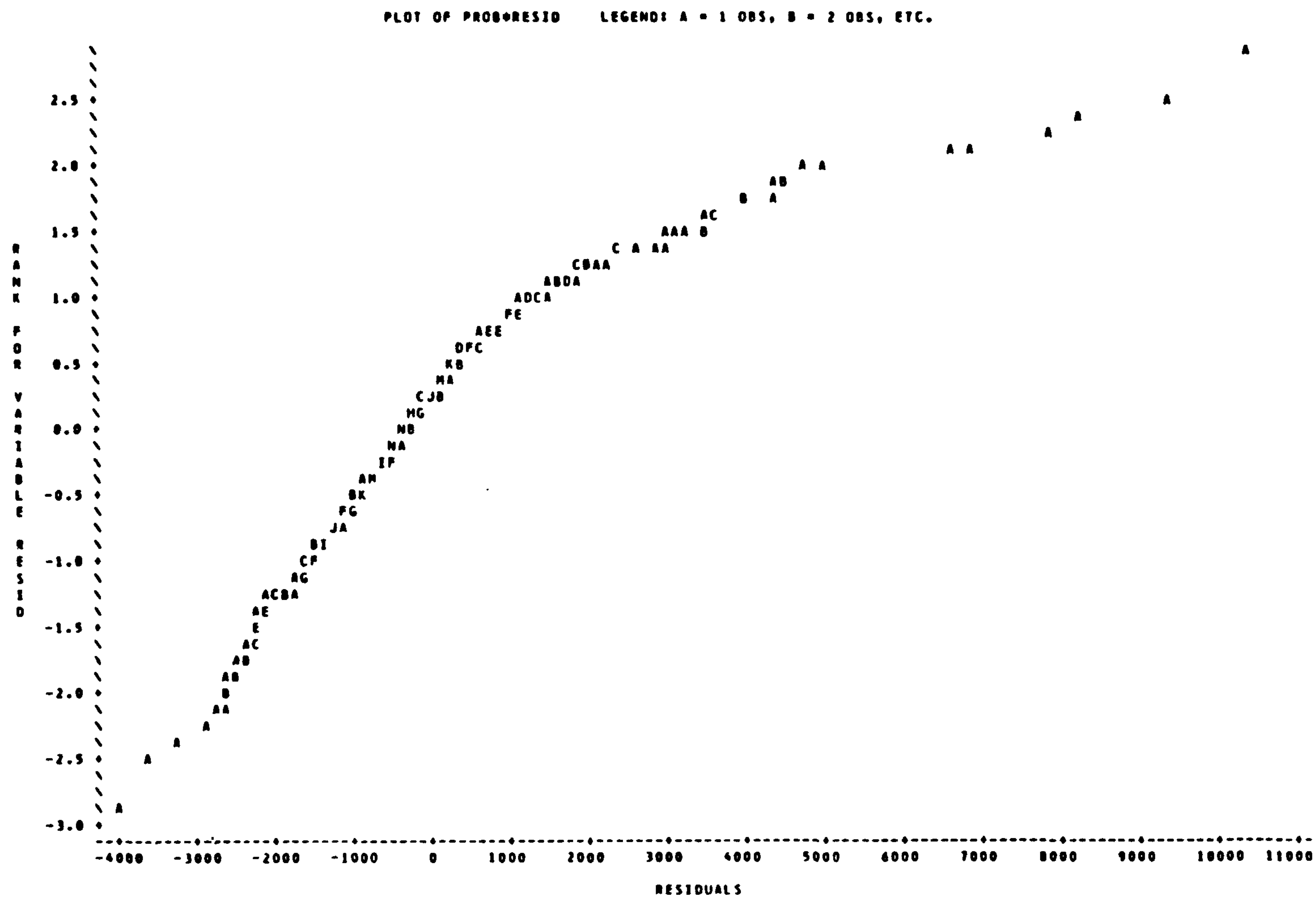

Fig. 7. Residual Probability Display (Untransformed) for Base 1

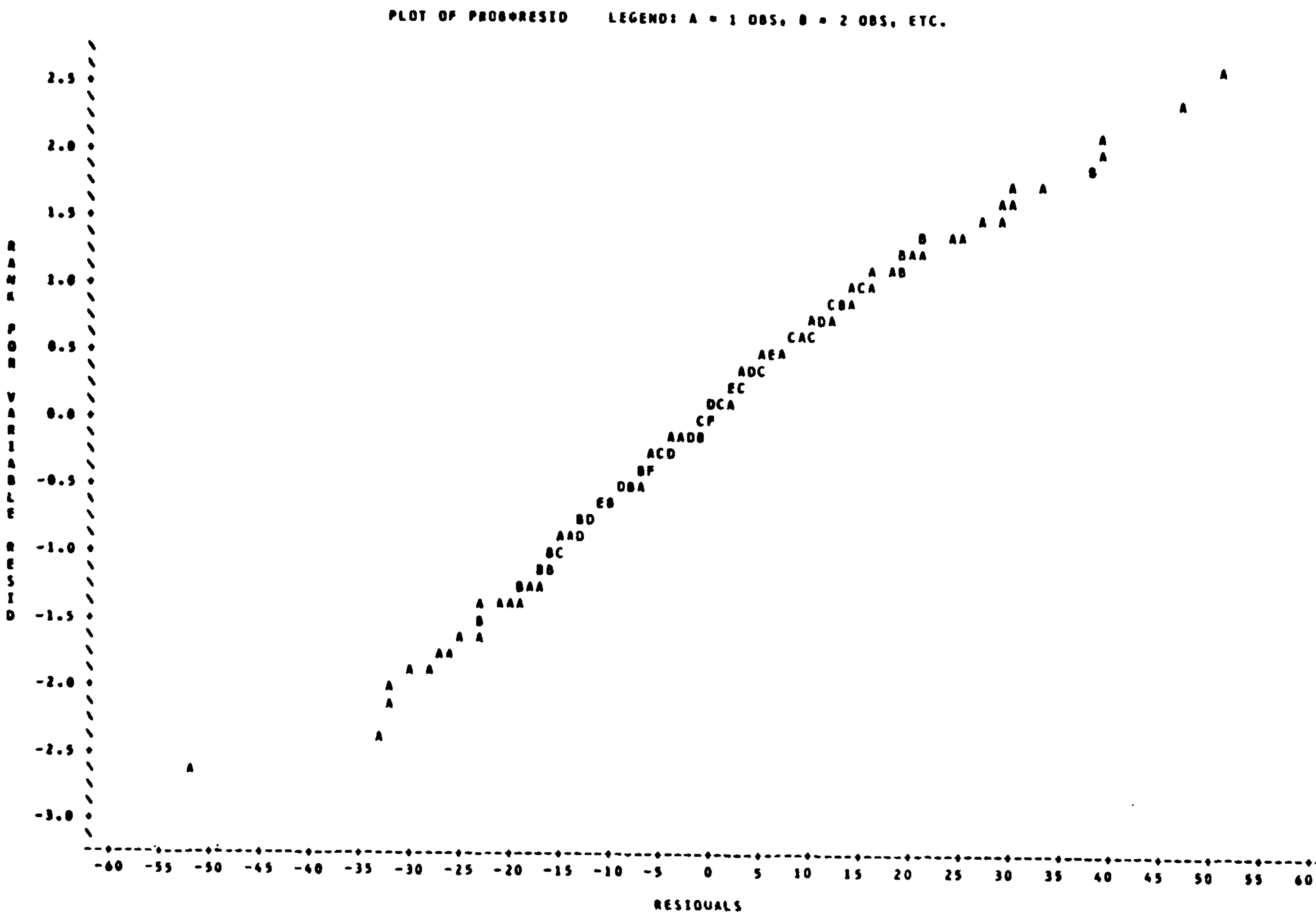

Fig. 8. Residual Probability Display (Transformed) for Base 1

Interpretation of the Model

The model developed in this study is represented by the following:

$$Y = 9.43 + 2.98\ X_1 + .0016\ X_2$$

where X_1 equals age and X_2 equals average miles, and Y as it has been transformed (through its square root), must be squared. Before discussing the relevance of this equation, the meaning of the Beta 0 (9.43) coefficient is discussed. The regression procedure used in this thesis recognizes the fact that the major independent variables do not give a total prediction of the dependent variable. As such, the Beta coefficient attempts to compensate the realm of the "unknown." This is done through the use of a β_0 coefficient. In this case, the β_0 coefficient (9.43) is inserted through the regression process. This insertion of the Beta coefficient, to the model, is the way the regression procedure compensates for the unknown factors which might affect the model (42).

So how does this translate into something a MAJCOM/LGT can use? It can predict future maintenance cost for an additional vehicle for X year and Y average miles. For example, it will cost approximately $986.58 to maintain an additional vehicle for one year at 12,000 average miles. This is derived from:

$$Y = 9.43 + 2.98\ (1) + .0016\ (12{,}000) = 31.41^2$$

$$\text{or } \$986.58$$

This can further be broken down as to give the MAJCOM/LGT an idea of just how much time and average miles a dollar of O&M can buy where:

$$Y = 2.98\ (.3355) = 1;\ .3355 \times 12 = \text{approximately 4 months}$$

and

$$Y = .0016\ (625) = 1 \times 625 = 625 \text{ average miles}$$

From this type of information the MAJCOM/LGT can decide to review such predicted costs at all subordinate bases. This type information can assist him in making his next allocation decision; however, since only two bases delivered data, this model can only demonstrate the potential for future application.

The last statistic to be discussed is the coefficient of determination (r^2). This brief discussion explains how it pertains to the model. The r^2 for this model was .3774. This means that X_1 and X_2 account for an estimated 37.74 percent of the variation of Y (the predicted maintenance cost), the dependent variable (41:22). Although this r^2 value is low, it does show that X_1 and X_2 do assist in explaining Y. Further, it indicates it is 37.74 percent better in predicting Y than if the means of Y had been used to predict Y.

The above information gleaned from the regression equation is useful; however, more information can be extracted from the model. Considering the average age of

the fleet at Hanscom is 6 years old, and the average miles traveled by each of the 167 vehicles in the sample was 8088 miles. The following equation can be drawn up to predict one additional year's maintenance cost:

$$Y = 9.43 + 2.98\ (X_1) + .0016\ (X_2)$$

where X_1 is one year and X_2 is 12,000 (expected average fleet miles per vehicle) = 31.61^2 X 167 vehicles equals 166,865. This means it will cost approximately $166,865 to maintain the general purpose fleet at Hanscom for one year, given each of the current 167 vehicles travel 12,000 average miles.

The last area to be reviewed pertains to the data. The SAS program, through its PROC PLOT procedure, plotted the total cost by the average miles driven (X_2). Figure 9 indicates a rising trend in the total cost until it reaches approximately $(70)^2$ $49,000 at 24,000 average miles. From this point it appears to level out. This could be a function of surge driving during the initial years of the vehicle.

Figure 10 shows there is a similar trend. Only in this instance the cost rises from years zero to three. Then it levels out to approximately $4,900. It maintains this level until year eight, then it appears to decrease. This could be attributed to the fact that most general purpose vehicles have six to eight-year life expectancies. Afterwards, these vehicles are usually salvaged.

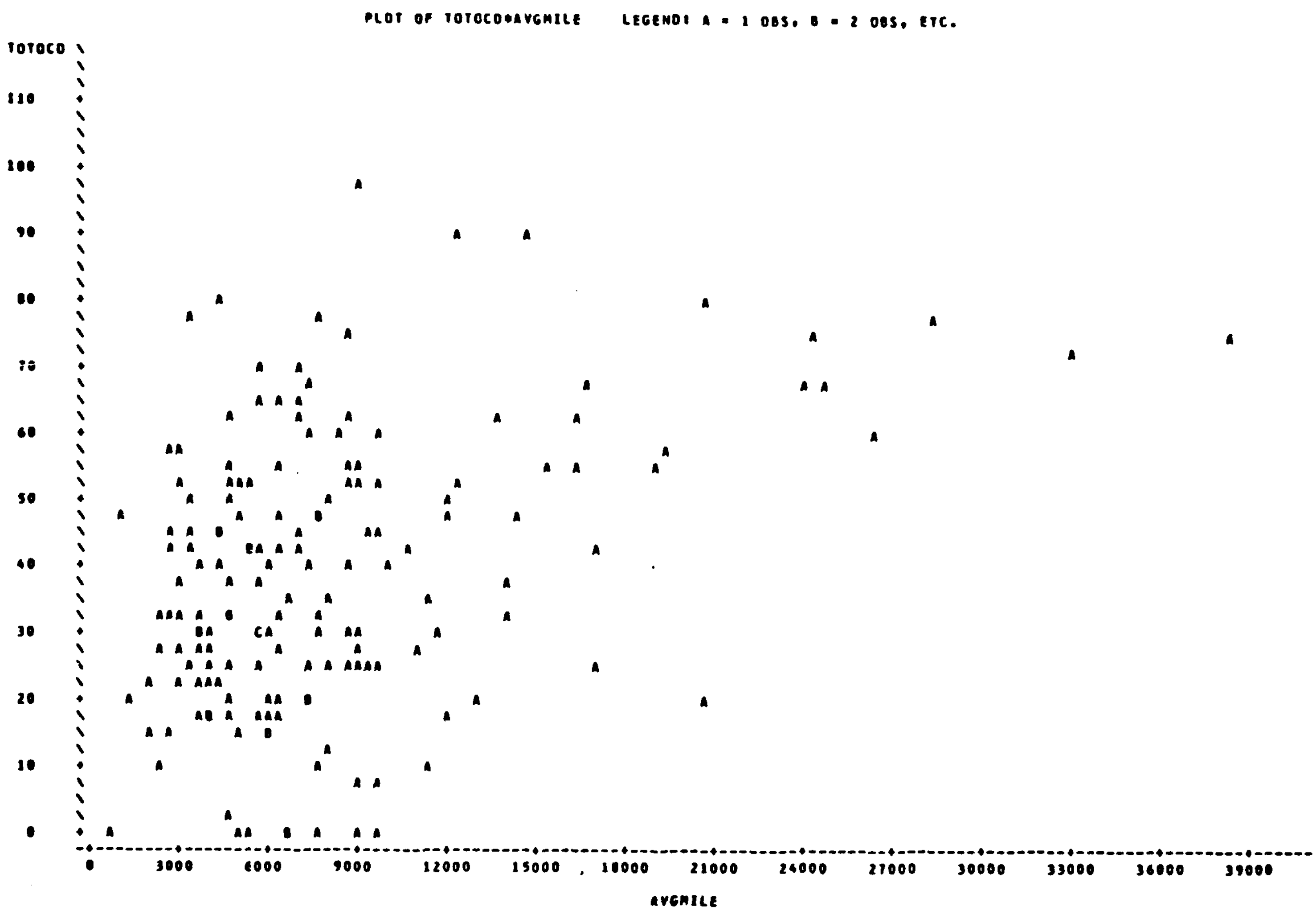

Fig. 9. Cost Trend for Base 1--Cost by Miles

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PLOT OF TOTOCO*AGE LEGEND: A = 1 OBS, B = 2 OBS, ETC.

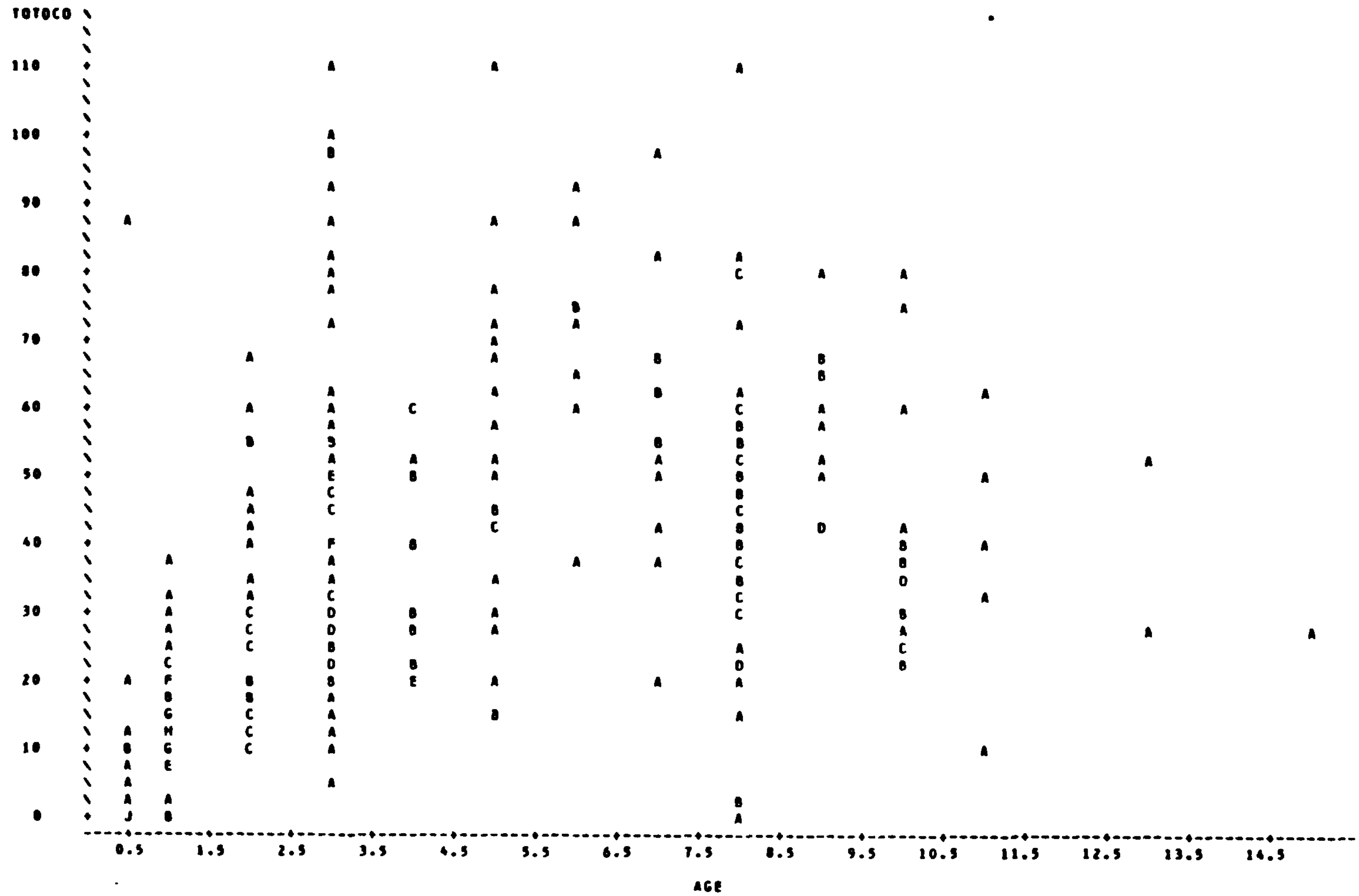

Fig. 10. Cost Trend for Base 1--Cost by Age

Results of Base 2

This discussion continues with an interpretation of the results from base 2 (Patrick). The primary considerations were the assumptions concerning the e term. The results concerning the e terms for base 2 were very similar to base 1. The test for the equal variance had results that were like the first base. The horn shape was clearly evident. This shape, as mentioned earlier, indicates an unequal variance of the error terms. This particular case indicates that the variance tends to increase with the regressors, X_1 and X_2, just as was the case for base 1. Figure 11 shows the residual chart represented in this situation.

In this case it was again decided to transform the dependent variable. The same transformation, taking the square root of the dependent variable, was used with similar results. The results of this transformation are detailed in Figure 12. This transformation establishes the equal variance of the error terms.

The next major assumption to be checked for pertained to the probability distribution. This test was conducted through the use of the SAS PROC RANK procedure. This procedure is the same as the one used for base 1. The results are shown in the following two figures. Figure 13 shows the model as it was applied to the raw data. This figure shows that the probability distribution of the

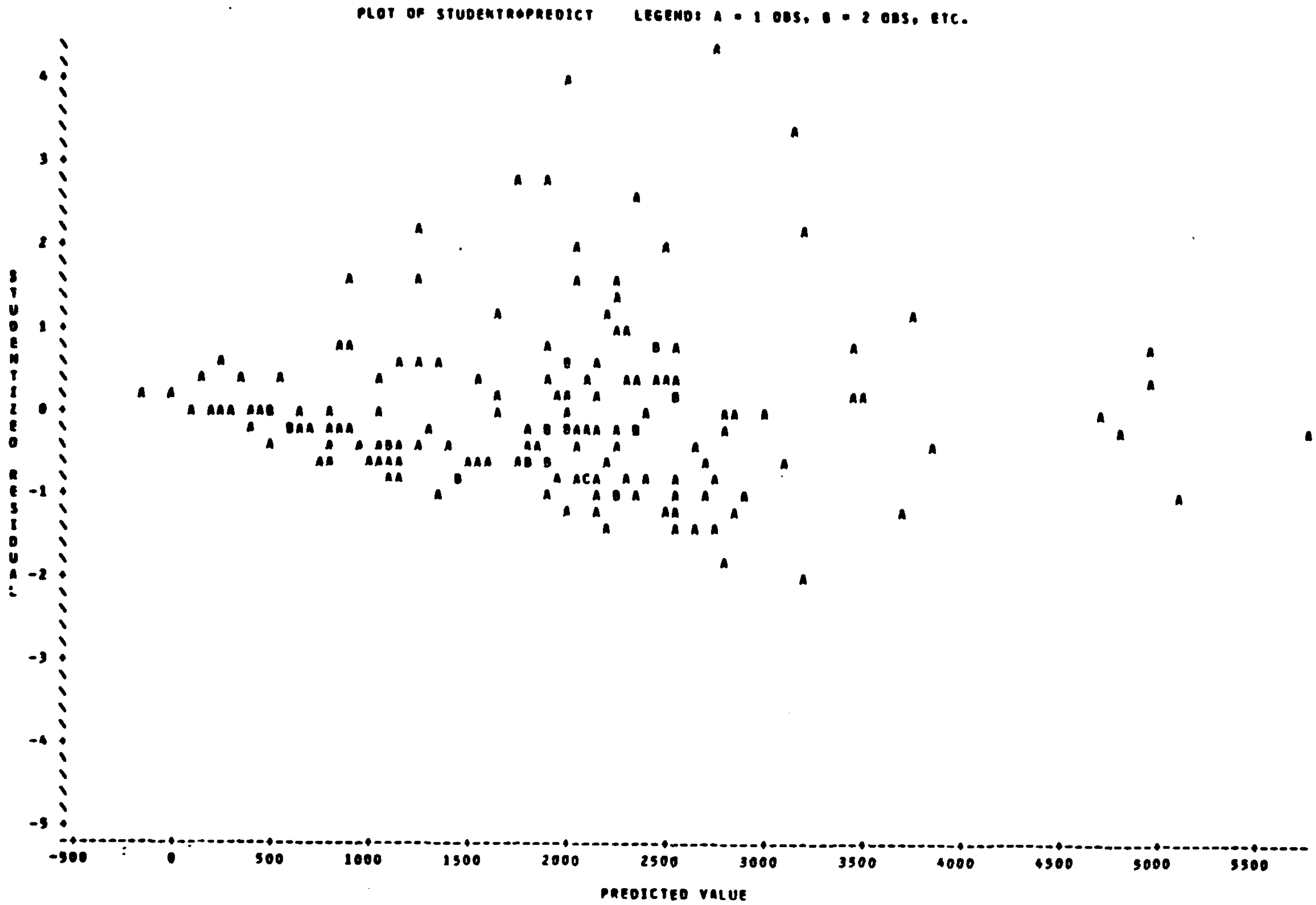

Fig. 11. Residual Variance (Untransformed) for Base 2

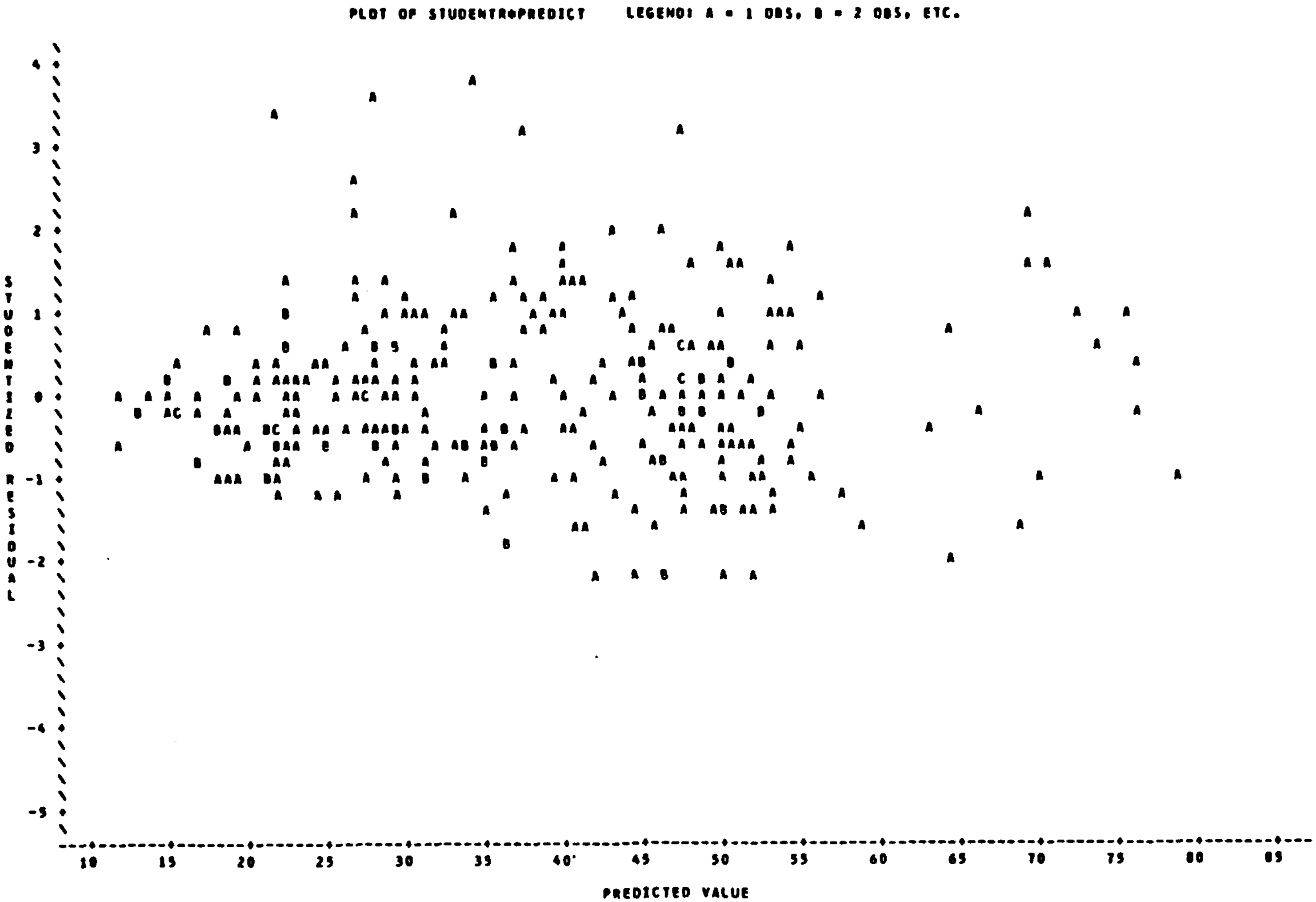

Fig. 12. Residual Variance (Transformed) for Base 2

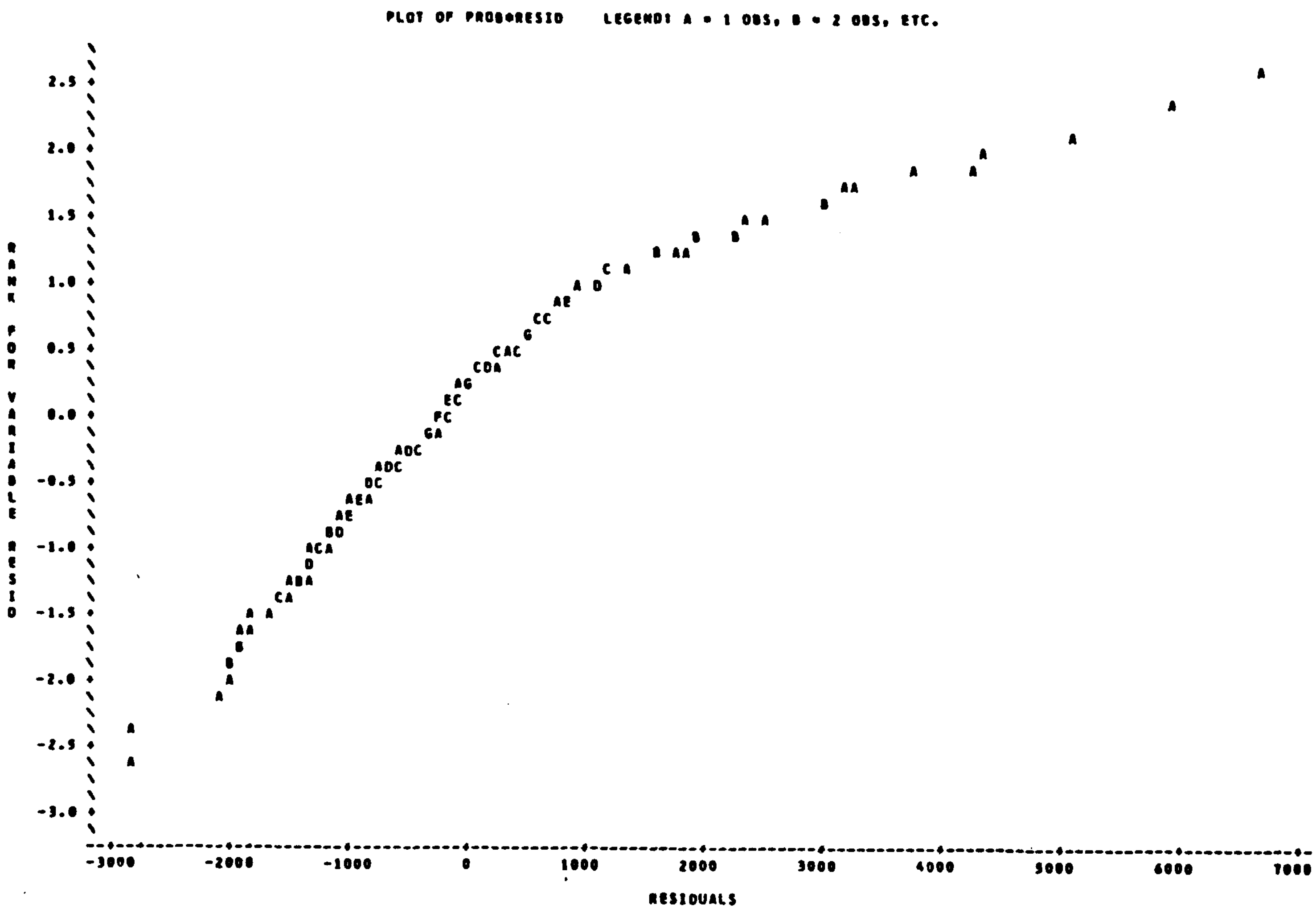

Fig. 13. Residual Probability Distribution (Untransformed) for Base 2

error terms are not normal; however, Figure 14 shows that the transformed data is from a normal probability distribution. With these two assumptions proven, the third one is assumed to be true.

Model Interpretation for Base 2

The model used for base 2 was the same as the one used for base 1. It is represented by the following:

$$Y \text{ (predicted maintenance cost)} = 7.80 + 3.8\ X_1 + .0021\ X_2$$

where X_1 equals age and X_2 equals average miles and Y, since it has been transformed by the square root, must be squared. This can be used to give the MAJCOM/LGT the following information costs. These costs represent the expected maintenance cost for an additional vehicle, going one year X_1 and 12,000 average miles X_2, at Patrick:

$$Y = 7.8 + 3.80\ (1) + .0021\ (12{,}000) = 36{,}08^2 \text{ or } \$1301.77$$

This can be further applied in predicting the next year maintenance cost. This can be done by taking:

$$Y = 7.8 + 3.80\ (1) + .0021\ (10{,}000 \text{ average miles}) = 32.6^2 \text{ or } \$1062.76 \times 306 \text{ (the sample size)} = \$325{,}205$$

This higher cost is probably a function of the larger fleet size at Patrick. This model can also be broken down further to give the decision maker an idea of how much his O&M dollar is worth. This is represented by:

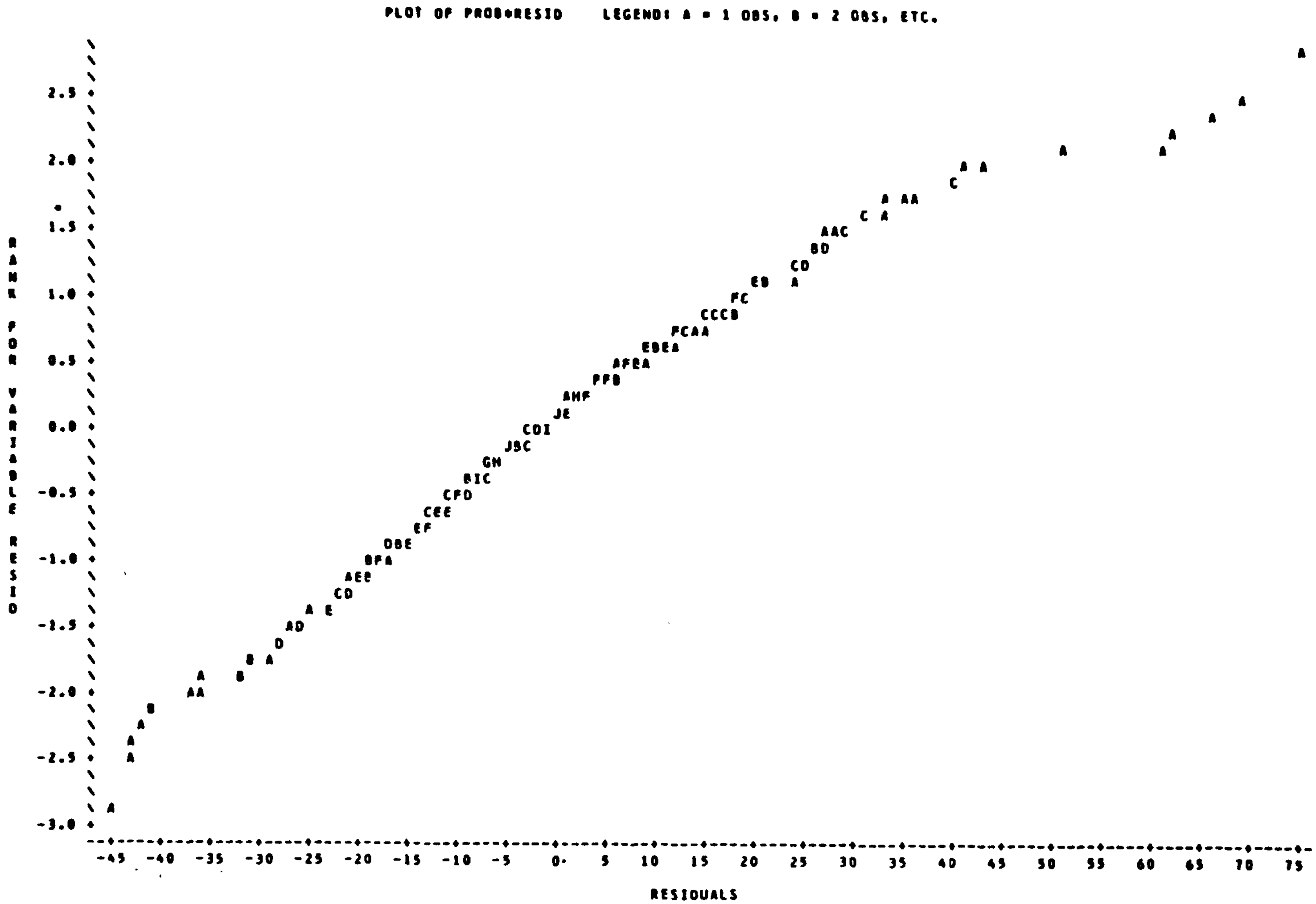

Fig. 14. Residual Probability Distribution (Transformed) for Base 2

Where $Y = 3.08\ (1/3.08) = .3246 \times 12 = 3.89$ or

about 4 months or

$Y = .0021\ (1/.0021) = 1 \times 476$

= approximately 476 miles

What this says is that basically the difference between the two bases is not that significant. The predicted maintenance cost for base 1 was different. This could be attributed to the fact that the fleet size at Hanscom is smaller or other factors outside the realm of this study. Also, while the amount of time each O&M dollar can obtain is similar, the number of miles is not; however, the difference is not that great. This too could be due to a larger fleet size at Patrick or other factors ancillary to this study. The point here is that the differences, as reviewed within the context of this study, are only slight.

The last area to be reviewed for base 2 pertains to the data. The data, through the use of the SAS PROC PLOT, is likewise compared in the following two areas. They are total cost plotted by the average miles and total cost plotted by the age of the fleet. The average miles appear to be a direct upward linear relationship. There appear to be a slight decrease at the 23,000 average mile point; overall, the costs appear to go past (80^2) $6400. This relationship is displayed in Figure 15. In this case, the age factor is different. It tends to upwardly increase

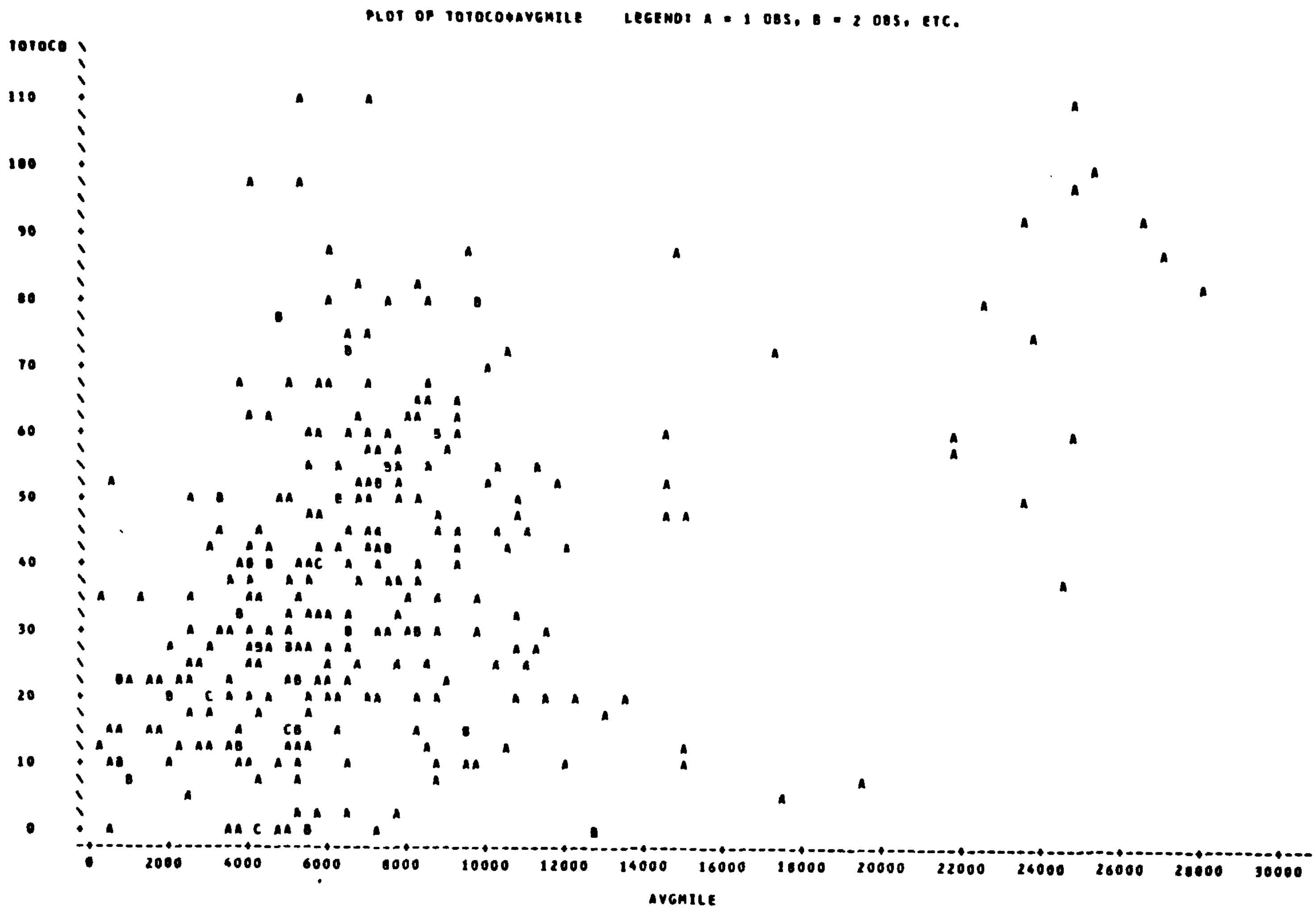

Fig. 15. Cost Trend for Base 2--Cost by Miles

to the \$6400 point and level out there until around year 11. This is demonstrated in Figure 16. This could be that Patrick keeps some of its general purpose vehicles past their life expectancy. Other factors outside the parameters of this study, may also contribute towards this difference.

Further reviewing the mean age and the mean average number of miles of the fleets indicates no real difference between the bases. The mean age of the fleet was 6 years at Hanscom, and 5 years at Patrick. The mean average miles also show little difference. The means were 8088 and 7224 miles, respectively. While this is a generalization based on limited data, it is an indication that the current "fair share" as practiced by the AFSC/LGT is an effective method of distributing general purpose vehicles.

Statistical Tests for the Model

Again, the statistical significance level selected for the following statistical tests used was .05. The F value for this model was 78.33. It is statistically significant at accounting for its ability to predict Y (the dependent variable). It is further validated by the t tests done on the individual Beta coefficients. The results were: $\beta_0 = 2.98$, $\beta_1 = 8.92$, and $\beta_3 = 9.33$. These scores indicate each coefficient contributes in predicting Y. The Cook's D showed no outliers and the tolerance of

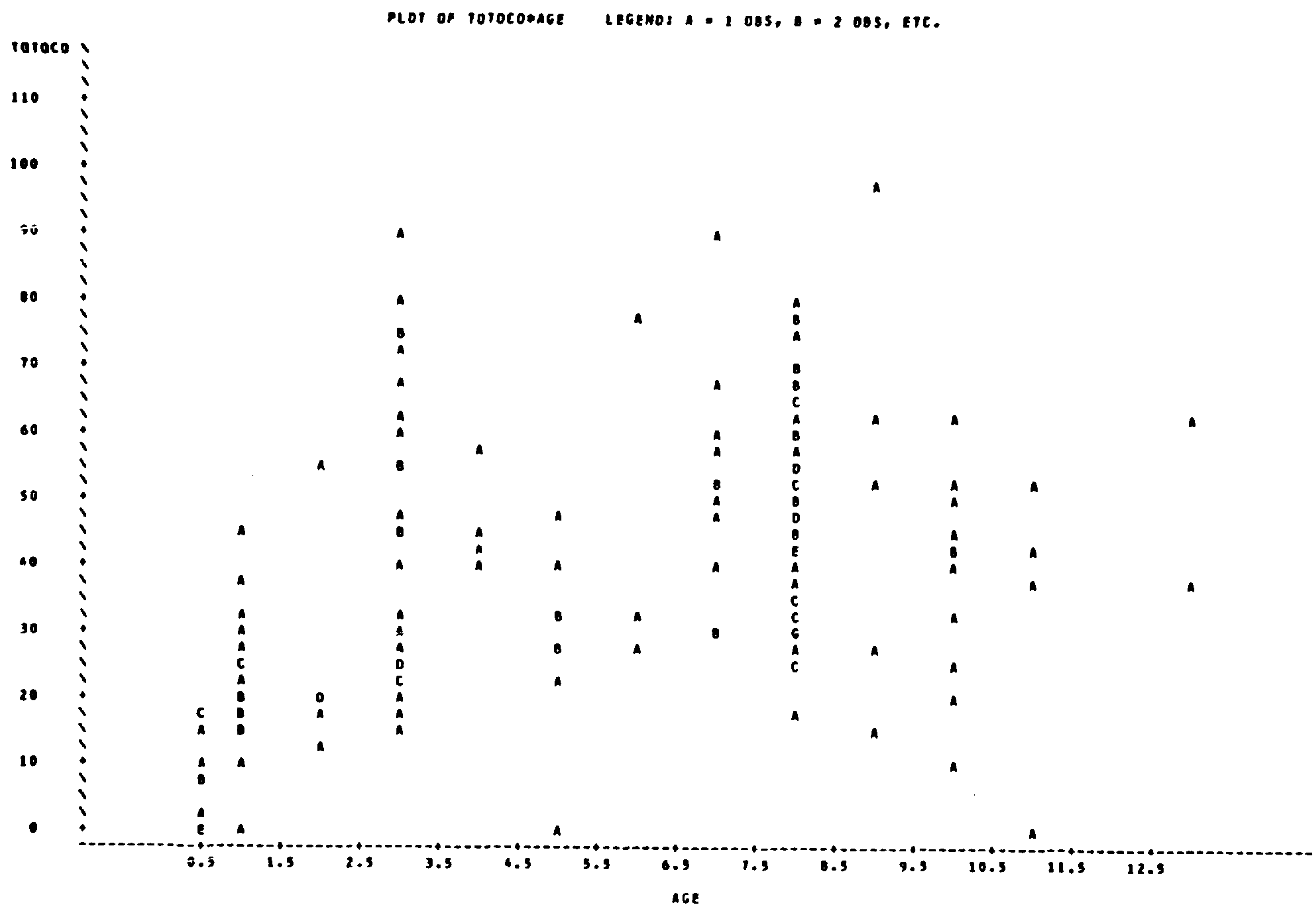

Fig. 16. Cost Trend for Base 2--Cost by Age

.99 ruled out any potential for multicollinearity. The Durbin Watson statistic, D = 1.51, for autocorrelation was inconclusive.

The last statistic to be mentioned is the coefficient of determination. For this model the r^2 was .3408. Again, this means that regressors, X_1 and X_2, account for an estimated 34.08 percent of the variance of Y (the dependent variable). Although this statistic is low, it does indicate that the model, using the regressors, is 34.08 percent better than if just the means of the data had been tried to predict Y. This model is a beginning in the attempt to quantify this process. While the β_0 absorbs some of the unknowns (42), it cannot account for all factors within the universe of vehicle transportation.

A Consolidated Model

Using the data sets from the two bases, a consolidated model was processed. The SAS PROC MERGE procedure merged the two data sets and resulted in the following equation:

$$Y = 9.09 + 2.98\ X_1 + .0018\ X_2$$

where X_1 is age and X_2 is average miles and Y is squared. This equation, given it meets the assumptions of the error terms, can predict the maintenance cost for a vehicle going one year at 12,000 average miles using the following:

$$Y = 9.09 + 2.98\ (1) + .0018\ (12{,}000 = 33.67^2 \text{ or } 1133.67$$

This means is for AFSC, based on this limited model, that a fleet of n vehicles traveling 12,000 average miles would approximately cost $1133.67 X n (number of vehicles) to maintain.

Again, it must be reemphasized that this model is only based on the consolidation of the two bases which submitted data. Therefore, this represents one method the MAJCOM/LGT can employ to see how the maintenance costs vary by base within the command. It can also be used to predict future maintenance costs for the command and if there is a significant difference, then allocation decisions can be made to place the vehicle accordingly. This would be a vehicle placement which reduces the overall fleet cost.

Additionally, the regression model can be used to determine the value of the O&M dollar. This can be done by the following:

$$Y = 2.98\ (1/2.98) = .3355; 3355 \times 12 = 4.026 \text{ or approximately 5 months}$$

and

$$Y = .0018\ (1/.0018) = 1; 1 \times 556 = 556 \text{ miles}$$

This can be another indicator to measure any significant difference within the command. From the sample, restricted to the two bases that delivered data, there is no real

significant difference. This statement is made considering the fleet size at base 2 is almost twice that of base 1.

The bottom line is that, from the limited sample, there is no real significant difference between the bases. The regression coefficients, as well as the mean ages and average miles traveled, indicate that the current system is effective. This is to say that the "fair share" method of distribution, as practiced by the AFSC/LGT, is just as effective in terms of long-term cost avoidance than anything the model could suggest. Although the data base severely limits the model from actually making any suggested allocations, it does not show any major difference between the regression (cost) lines of the two bases involved.

Statistical Tests of the Model

The transformed data met the assumptions of the error term. Likewise, all other aspects of the model are statistically significant. This only follows as it was based on the transformed dependent variable as previously defined. The same kind of statistical results as previously discussed apply here only the actual values differ. The F value for the consolidated model was 122.97. The Beta coefficients were: $\beta_0 = 4.49$; $\beta_1 = 11.45$; and $\beta_2 = 11.43$. These results indicate that the model and its coefficients are effective at predicting Y. The r^2 for this model was .3435. This indicates that this model was

34.35 percent better at predicting Y than if the mean values had been used.

This analysis indicates that the model used in this thesis is an effective one at predicting Y. While it is limited to a degree by the low r^2 values, it is an alternative method at predicting maintenance costs. As mentioned earlier, it appears that this model can be a quantitative tool which can assist the decision maker in making allocation decisions. This on the premise that cost avoidance is the driving factor behind the decision.

The last area under study, pertinent to the models presented, is what, if any, degree is there interaction present between the independent variables. Interaction between variables is defined as:

> Two variables X_1 and X_2 are said to interact if the change in E(Y), the expected value for Y, for a 1-unit change in X_1 (when X_2 is held fixed) is dependent on the value of X_2. (35:527)

The method used to determine this condition was the SAS PROC GLM procedure (38:432). The results were mixed. It appears that there is no interaction between the regressors at Hanscom. On the other hand, there does appear to be some interaction between age and average miles at Patrick. The significance of this condition is the effect it has on the β_0 coefficient. At Patrick it raises the β_0 coefficient from 7.8 to over 14. This difference could be accounted for in the sample size of the fleets involved; however, the consolidated model did not show any

interaction. This may then be a result of outside parameters. These parameters may or may not be unique to the environment at Patrick. The focus of the discussion will now shift to the investigative questions raised in Chapter I.

Investigative Questions

The following investigative questions raised in Chapter I will now be addressed. The first was how do MAJCOMs currently allocate new general purpose vehicles? Currently MAJCOM/LGT's use the "fair share" method of distribution. This entails, as highlighted in Chapter II, using the priority buy program to keep the subordinate base fleets balanced. As seen from the two bases in this study, the means fleet ages and average miles traveled were in fact similar. This would indicate there is a conscious attempt, at least on the part of the AFSC/LGT, to employ this strategy.

The second question raised pertained to the measurement of the "fair share" method. Specifically, how is the effectiveness and efficiency of the "fair share" method of distribution currently measured? The current system is measured through the use of a qualitative management system. This system is basically the interaction between the bases and the MAJCOM/LGT. There is no formal evaluation process; however, a skewed distribution of vehicles would reflect in higher O&M costs at the affected base(s).

The third and fourth questions pertain to the model. Can the proposed model demonstrate a distribution which can place the next general purpose vehicle where it will reduce the overall fleet cost? Unfortunately, with the low response rate no macro statement can be made about an alternate method of distribution. The last question pertains to the process. Is the new model a valid approach to the problem of finding an effective and efficient method of allocation of vehicles to bases? Again, due to the small sample, no macro statement can be made on this question. What can be said is that the model, through its limited data base, did appear to validate the current system of allocation.

Summary

This chapter began with an analysis of the model results from base 1. After a thorough discussion it went through the results of base 2. Next, a consolidated model was run and the results of the model were presented. The limitations of the small sample size were mentioned. Then a review of variable interaction was presented. Finally, the investigative questions posed in Chapter I were discussed.

V. Conclusion

Introduction

This study focused on the development of a regression model which could be used by MAJCOM vehicle managers to aid in their allocation of general purpose vehicles and excluded other types of vehicles. By using the model and comparing its indicators, i.e., O&M dollar value, predicted maintenance cost, the allocation decision made can be reviewed across the subordinate bases. If this review indicates any substantially higher costs or differences in the O&M dollar value, then allocations can be made to balance the fleet.

Research Question

While the investigative questions were presented for discussion in Chapter IV, it is here that the basic research question will be addressed. For it was the driving factor behind this research effort. So, how should general purpose vehicles be allocated to bases, by a parent MAJCOM, so that performance and cost are explicitly considered. Based on the limited sample size it appears the current method of distribution is an effective one. This is to say that considering the major tenet of this

thesis cost avoidance (savings) the current system as practiced in Systems Command is effective.

The current effort of the AFSC/LGT to keep the AFSC fleet balanced appears to be working. Considering that performance is directly impacted by the level of maintenance and the funding available to do so, it appears the status quo is not an ineffective way to proceed. From the results of the model it appears that there are no current significant differences between the sample bases. The lack of significant differences in mean fleet age and average miles traveled as well as in the regression coefficients, indicate an effective distribution system. The limited sample size may have an effect on the model; however, the cost measures as determined by the model indicate little difference between the two bases. This is considering the fact that Patrick has a fleet that is almost twice the size of Hanscom. This could be due to the considerations given, to location and mission, by the MAJCOM/LGT when he makes his allocation decisions.

This model provides the MAJCOM decision maker an alternative method at reviewing allocation decisions. This model could, as in this case, validate the method used or suggest through the higher cost lines of other bases an alternative method. The cost of using the model is relatively small and the potential gains are both short and long term. The minimum cost of using this model is

highlighted by the fact that scarcity of resources will continue to be a way of life for Air Force managers.

There are several areas that would make ideal candidates for future research. They are:

1. Using the model with a complete set of data (PCN 32 reports) from all bases within a command.

2. Applying the model to other commands.

3. Eventually establishing an Air Force-wide data base and rerunning the model.

In summary, this model has shown that there is room for addition of quantitative tools to the allocation of vehicles. It has demonstrated two major factors. One is that the data, through the transformation of the dependent variable, does meet the criteria established for using linear regression. Two, the model can and should be developed, in future research, to include other variables.

Appendix A: Vehicle Replacement Codes: AFTO 00-25-249
(Vehicle Management Index File)

RC	Criteria
U	Vehicle is under new/remanufactured warranty.
T	Assigned when codes A through U do not apply. In effect, when vehicle lies between U and R.
R	Vehicle has reached or exceeded half of its programmed life expectancy in years.
Q	Vehicle will reach its life expectancy in miles within two years.
P	Vehicle will reach its life expectancy in years within two years.
N	Vehicle will reach its life expectancy in miles and years within two years.
M	Vehicle will reach its life expectancy in miles within one year.
L	Vehicle will reach its life expectancy in years within one year.
K	Vehicle will reach its life expectancy in miles and years within one year.
J	Vehicle has reached or exceeded its life expectancy in miles.
H	Vehicle has reached or exceeded its life expectancy in years.
G	Vehicle has reached or exceeded its life expectancy in miles and years.
D	Vehicle has reached or exceeded its One Time Repair Limit (OTR).
C	Vehicle has reached or exceeded its life expectancy in miles and its OTR.
B	Vehicle has reached or exceeded its life expectancy in miles, years and its OTR.

Appendix B: Vehicle Life Expectancies (AFTO 36A-1-1301)

Management Code	Vehicle Type	Life Expectancy	Mileage Expectancy
B 102	Sedan, Compact	8 years	72,000
B 104	Sedan, Mid Size	8 years	72,000
B 106	Sedan, Law Enforcement	4 years	120,000
B 119	Bus, 28 Passenger, GED (Gasoline Engine Drive)	9 years	83,997
B 121	Bus, 28 Passenger, DED (Diesel Engine Drive)	14 years	200,004
B 130	Bus, 44 Passenger, DED (Diesel Engine Drive)	14 years	200,004
B 141	Bus, Ambulance, 44 Passenger	12 years	70,000
B 150	Station Wagon, Compact	8 years	72,000
B 163	Ambulance, Modular, 4x4	13 years	59,995
B 165	Van, Ambulance	8 years	60,000
B 168	Panel Van	8 years	72,000
B 176	Multi-Stop	7 years	72,002
B 185	Carry All, Nine Passenger	7 years	72,002

Management Code	Vehicle Type	Life Expectancy	Mileage Expectancy
B 193	Carry All, Suburban	8 years	100,000
B 204	Pick Up Truck, 4x2	7 years	72,002
B 217	Pick Up Truck, 6 Passenger, 4x2	8 years	72,000
B 222	Pick Up Truck, 6 Passenger, 4x4	6 years	72,000
B 233	2.5 Ton Truck, Cargo, 4x2	8 years	84,000
B 255	2.5 Ton Truck, Cargo, 6 Passenger, 4x2	8 years	72,000
B 261	One Ton Truck, Cargo	8 years	72,000
B 263	1.5 Ton Truck, Cargo	9 years	65,997
B 352	5 Ton Truck Tractor, GED (Gasoline Engine Drive)	11 years	149,996
B 353	5 Ton Truck Tractor, DED (Diesel Engine Drive)	11 years	149,996
B 361	10 Ton Tractor, 6x4, 44,500 pounds	12 years	150,000
B 363	10 Ton Tractor, 4x6, Nonrated	12 years	150,000
B 401	25 Foot Trailer, Tilt Deck, 22 ton	25 years	25 years
B 407	25 Foot Trailer, 20 Ton	25 years	25 years

Management Code	Vehicle Type	Life Expectancy	Mileage Expectancy
B 409	40 Foot Trailer, 20 Ton	25 years	25 years
B 411	Semi Trailer, 20 Ton	25 years	25 years
B 423	Semi Trailer, Van, 32 Foot	25 years	25 years
B 444	Tilt Trailer, 6 to 8 Ton	25 years	25 years

NOTE: The mileage expectancy was derived by multiplying the AFTO's directed life expectancy by the annual directed expectancy.

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Vita

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The purpose of this research was to develop a mathematical model which could assist in the allocation of general purpose vehicles. The linear regression model developed was used, through the AFIT CSC computer system, within the SAS statistical software program.

Data was obtained from two AFSC bases. Their input, through the SAS interaction, led to the following model:

$$Y \text{ (predicted maintenance cost)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

where X_1 equals age and X_2 equals average miles driven. The analysis demonstrated the statistical significance of the model. It also highlighted the potential for its application to include all bases within a command. The data limitation, only two bases in the sample, restricted the analysis from making any macro statements; however, it appears from the minor differences in regression coefficients, as well as similar mean fleet ages and mean miles traveled, the current distribution system is an effective one. This is to say that the current system of allocation used by the AFSC/LGT, the "fair share" method is effective at keeping maintenance costs, as well as vehicle assets, balanced across the AFSC fleet.